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HIGH FREQUENCY SIGNAL SOURCES USING SURFACE ACOUSTIC WAVE (SAW)--ETC(U)
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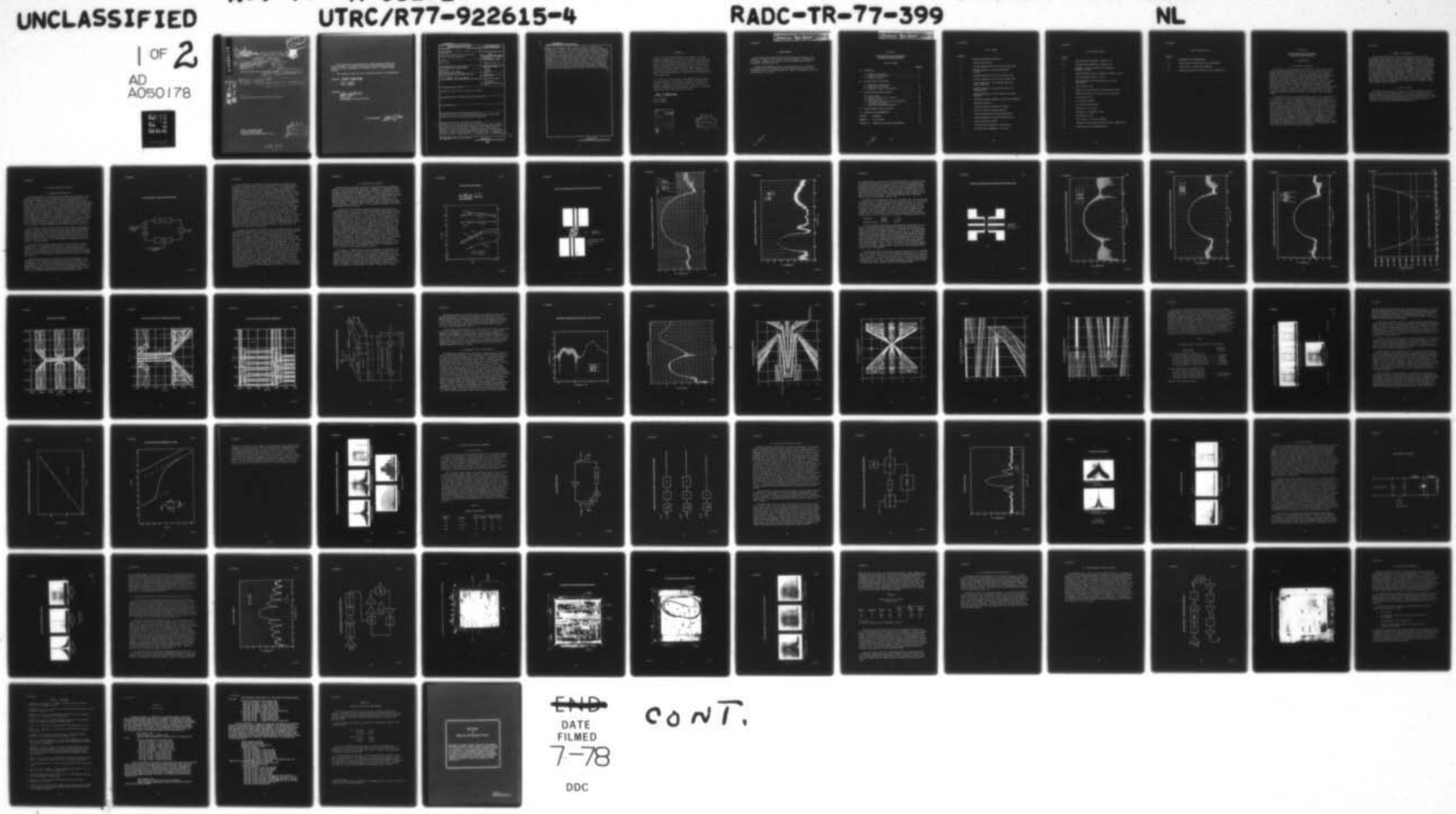

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# HIGH FREQUENCY SIGNAL SOURCES USING SURFACE ACOUSTIC WAVE (SAW) TECHNOLOGY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Stabilized comb spectrum generators using SAW Technology have been developed for operation at 333 MHz and higher frequencies. These signal sources and an additional CW source at 1984 MHz are being developed to provide precision signals for a rapid frequency hopping frequency synthesizer. The comb spectrum generator is based upon the Mode Locked SAW Oscillator (MLSO), a regenerative rf pulse oscillator. Stabilization, i.e., synchronization to a 1 MHz reference

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signal, is accomplished through injection locking of the MLSO at the fundamental rf frequency. The stabilization signal is provided by means of a Phase Locked Loop oscillator that is assembled from commercially available IC components. The first complete prototype consists of two four inch square circuit boards and consumes about five watts of power. This first prototype operating at 333 MHz generates the desired spectral lines (9 lines spaced 3 MHz apart) and the signal characteristics closely satisfies the goals of the program both for low FM noise and spurious signals. The judicious use of SAW filters was important for meeting the program goals. These SAW filters together with the IC components made possible a small compact package that can be even further reduced in size with further development. Preliminary results with the 828 MHz MLSO and the 1984 MHz CW source are also promising.

## EVALUATION

1. This is the Final Technical Report on the contract. It covers research to demonstrate the feasibility of generating comb spectra in the 300 to 900 MHz frequency range using a surface acoustic wave (SAW) delay line and an amplifier in a recirculating loop. Previous work with SAW oscillators has generated only a single frequency at a time. In the research reported here, a non-linear circuit element has been added to allow both maintenance of a broad spectrum and synchronization to an external clock.

2. This work is in direct support of the RADC/EEA in-house frequency synthesizer program. It has promise of providing the required comb spectra at significantly reduced size, weight, cost, and power consumption as compared with other approaches. However, it is of general applicability wherever comb spectra are required.

Alan J. Budreau

ALAN J. BUDREAU
Project Engineer

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## ACKNOWLEDGEMENTS

The following staff members at UTRC contributed to various aspects of the program: D. E. Cullen, T. W. Grudkowski, H. Knickerbocker, G. K. Montress, and T. M. Reeder. Thanks are also due to W. Kerns at RADC/ETEM (Hanscom AFB) for fabricating the 828 MHz delay line.

Finally, acknowledgement is made of the meticulous work of B. Bujnarowski in fabricating most of the SAW delay lines and filters and especially of the many tedious hours in the laboratory spent by R. Rukus in uncovering and evaluating the characterics of the MLSO.

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High Frequency Sources Using Surface Acoustic Wave (SAW) Technology

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# High Frequency Sources Using Surface Acoustic Wave (SAW) Technology

## 1.0 INTRODUCTION

### 1.1 Objectives and Approach

The objective of this program was to develop a set of high frequency signal sources, using SAW technology, that are synchronized by injection locking to a highly stable low frequency crystal oscillator. The signal sources include: 1) a Mode Locked SAW Oscillator (Ref. 1) at 333 MHz generating a comb spectrum with 9 precision lines spaced by 3 MHz, 2) a Mode Locked SAW Oscillator at 828 MHz generating a comb spectrum with 10 precision lines spaced at 24 MHz, and 3) a single frequency source at 1984 MHz. These three sources will provide the primary signals for a new approach to frequency synthesis that is made possible by the electronically controlled SAW filter technology under development at RADC/ET, Hanscom AFB (Refs. 2, 3, 4). A complete description of the noise and spurious signal requirements is given in Appendix II. In order to take advantage of the compact and small size possible with SAW technology, the SAW delay lines in the signal sources are integrated as much as is possible with components that are equally compact.

The MLSO is a SAW delay line oscillator which, because of the long delay time in the feedback loop, $\tau_a$, can oscillate simultaneously at a set of harmonics of $f_o = 1/\tau_a$ (Ref. 1). With the introduction of an amplitude expander, which favors the higher amplitudes in a pulse, a circulating rf pulse that is initiated into the feedback loop can not only be maintained but it becomes reduced in width to a pulse width determined by the net circuit bandwidth. The high frequency Fourier components of this circulating pulse are all harmonics of $f_o$ and they become the lines in the desired spectrum. The important effect applied to this new type of oscillator is injection locking at either a low order subharmonic or the fundamental rf frequency. A subharmonic input signal in the neighborhood of the frequency $f_o = 1/\tau_a$ can lock the oscillator to its frequency so that the high frequency components in the comb spectrum become exact harmonics of the input frequency. Alternatively, a signal at one of the comb lines can "lock" all of the lines and corresponding force the pulse repetition frequency to be an exact subharmonic. According to injection locking theory, the locking bandwidth is proportional to the ratio of the input to output voltages as referenced to a common set of terminals.

## 1.2 Summary of Work Completed

In this work on SAW signal sources a comb spectrum source evolved that consisted of a Phase Locked Loop Oscillator, a frequency tripler and a Mode Locked SAW Oscillator (MLSO) injection locked at its fundamental rf frequency. The Phase Locked Loop Oscillator and the frequency tripler provide the stable high frequency reference signal derived from a low frequency reference. This choice of component parts represents an optimum combination of technologies in terms of compactness and low cost. Special SAW filters contributed to the compactness of the design. The order of frequency multiplication was held to a minimum and the MLSO was improved in that it was self starting. The conventional expander in the MLSO was replaced by a simple transistor amplifier operating at a low bias voltage. The major effort was concentrated on the 333 MHz comb generator. A first prototype was completed and successfully tested, showing that it can meet the noise and spurious signal specifications goals. The other SAW signal sources, which were prepared in breadboard format, provided encouraging results on the operation of a MLSO at 828 MHz and a multiplier chain for 1984 MHz.

## 1.3 Contents of Report

This report discusses first, in Section 2.0, the Mode Locked SAW Oscillators, injection locking, and the various SAW delay lines. Then in Section 3.0, the complete stabilized comb spectrum generator is discussed including the Mode Locked SAW Oscillator, the reference signal generator and the required SAW filters. Finally, the design of the 1984 MHz single frequency source is included in Section 4.0, Section 5.0 contains the conclusions and recommendations.

## 2.0 THE MODE LOCKED SAW OSCILLATOR

### 2.1 Synchronized MLSO Operation

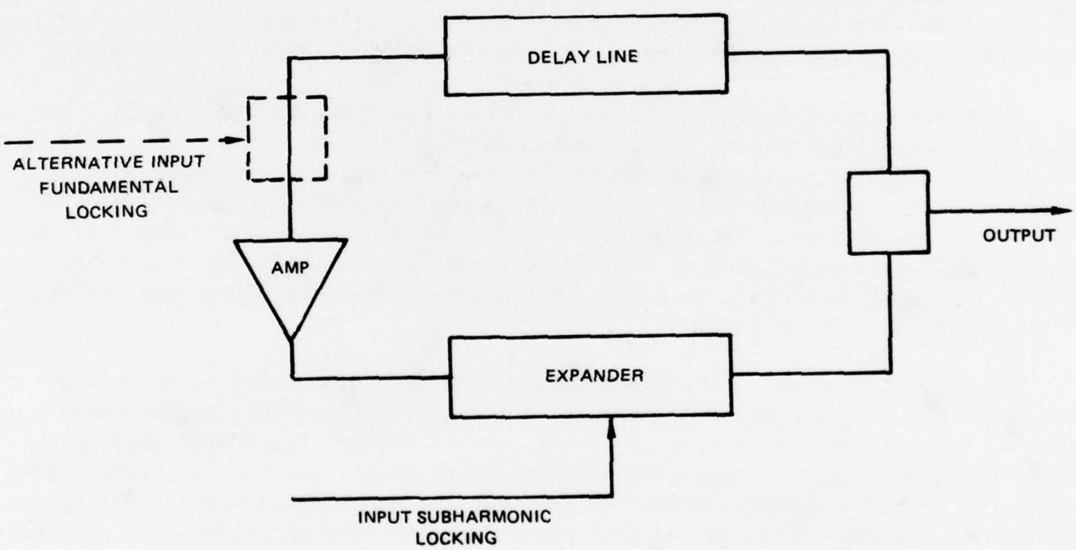
The synchronized MLSO is an extension of the signal source described in Ref. 1 in that it is modified so as to be controlled from a stable external source. In this program a reference signal at 1 MHz is provided. The basic circuit of the MLSO in Ref. 1 consists of a broadband delay line, an amplifier and an expander all connected to form a feedback loop, Fig. 1. With the loop gain for large level signals equal to 0 dB, and the conditions for self sustained oscillations met for a sequence of closely spaced rf lines (i.e., the round trip delay time is a multiple of the rf periods), a short pulse can circulate indefinitely around the loop with a repetition period equal to the SAW delay time. The function of the expander is to prevent the natural tendency for the pulsewidth to increase, as it circulates, by reshaping it at each pass so that it approaches the narrowest possible width (Ref. 1). It does this by emphasizing or expanding the large amplitude portions of the pulse. Because the rf frequency in this type of circuit must be a harmonic of the pulse repetition rate, the pulse envelope and the rf carrier are completely synchronized. In a sense, the MLSO has a memory extending over many repetition periods. This results in a high degree of coherence between the pulse envelope and the rf wave train.

In the circuit of Fig. 1, both the amplifier and the expander are nonlinear elements. Therefore, through nonlinear interaction, the concept of synchronizing the MLSO to an external reference signal becomes possible. The presence of the reference signal actually forces synchronization of the MLSO so that its rf frequencies and pulse repetition frequency are precisely harmonically related to the injected reference signal. This well known phenomenon is subharmonic injection locking or injection locking in a more conventional sense depending upon the frequency of the injected signal.

The general details of the synchronized MLSO are illustrated by the block diagram in Fig. 1. The expander circuit includes a varactor (as the nonlinear element) that is integrated with the delay line at the SAW transducer (Ref. 1). The presence of a large signal (the circulating rf pulse) and the reference signal causes the required expander action to maintain the short pulse width. The desired comb spectrum signal is extracted from the oscillator loop by introducing a coupler into the loop.

Some technical difficulties in obtaining the desired MLSO operation for the requirements of this program are associated with the short circulating rf pulses. For example at the 333 MHz range, the circulating pulse must have a width of approximately 30 nsec while at the 828 MHz the circulating pulse must have a width of approximately 4 nsec. The latter case becomes a challenging problem in the design of the expander and the associated pulse shaping network. For this reason the circuit development concentrated first on the 333 MHz signal source.

BLOCK DIAGRAM – INJECTION LOCKED MLSO

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The synchronization of the MLSO by injection locking to a reference signal must provide frequency stability when the temperature of the environment changes. In general, for each rf line in the spectrum, the value of the 3 dB bandwidth for the frequency response of the external circuit, including the SAW delay line (considered as a resonator), must be larger than the anticipated frequency drift. In this regard, ST cut quartz near room temperature would provide a relatively small frequency drift; however, because of its weak piezoelectric coupling, useful large bandwidth transducers cannot be realized. Two different bandwidths are being discussed here -- one is that associated with the equivalent resonant circuit Q due to time delay in the loop, $(\Delta f)_d = fo/Q = 1/(\pi t_d)$, while the other bandwidth, $(\Delta f)_t$, is that associated with the frequency passband of the delay line transducers. For a comb generator, $(\Delta f)_t$ must encompass the entire series of comb frequency lines. For the 333 MHz comb generator, since, $t_d = 333$ ns, $(\Delta f)_d = 0.96$ MHz while for the 828 MHz comb generator, $t_d = 44.4$ ns so that $(\Delta f)_d = 7.62$ MHz. For $LiNbO_3$ and a temperature change of 25°C, an oscillator would drift 0.825 MHz at 333 MHz and 2.07 MHz at 828 MHz. Thus $LiNbO_3$ easily satisfies the higher frequency comb generator requirements since the external circuit delay line bandwidth is more than three times larger than the anticipated temperature drift. This is an important observation because the band pass requirement of approximately 33 percent for the delay line transducers at 828 MHz can only be readily achieved with $LiNbO_3$. At the frequency of 333 MHz the required transducer bandwidth of approximately 10 percent can be achieved with quartz and the frequency drift with temperature would fall well below the value of 0.9 MHz for the resonator bandwidth. In this program it was decided to use $LiNbO_3$ for both delay lines.

An estimate can be made of the FM noise level for the mode-locked SAW oscillator by extrapolating experimental and theoretical results available for single frequency delay line oscillators. First recall that spectral noise near the carrier is primarily FM in nature and that it is due to noise generated in the amplifier (Ref. 5). As an example, consider noise to carrier ratios one kHz from the carrier that have been reported to be approximately -100 dB per Hz for the 60 MHz and 396 MHz SAW delay line oscillators by Lewis (Ref. 6) and Burnsweig (Ref. 7), respectively. Now, since the amplifier saturation level determines the amplitude of the CW oscillations, one would expect that the same circuit when operating as a mode-locked oscillator would have all of the spectral line amplitudes adding to give this peak pulse amplitude. Thus, the signal to noise voltage ratio for a single line should be reduced by approximately a factor of $N^{-1}$ (where N is an effective number of lines) from the single frequency CW case. For example, if fourteen prominent CW spectral lines are generated, each line would be 23 dB down from the single line case and the noise to carrier ratio at 1 kHz from the carrier would become -77 dB per Hz for the examples cited above. This value is below the -64 dB per Hz value given in the specified goals of the program, (Appendix II). This value of -77 dB per Hz may be an upper bound because in conventional injection locking, the FM noise level near the carrier lines becomes that of the input signal. Section 3 includes a discussion of the noise of a Phase Locked Loop oscillator which is used to provide the injected signal.

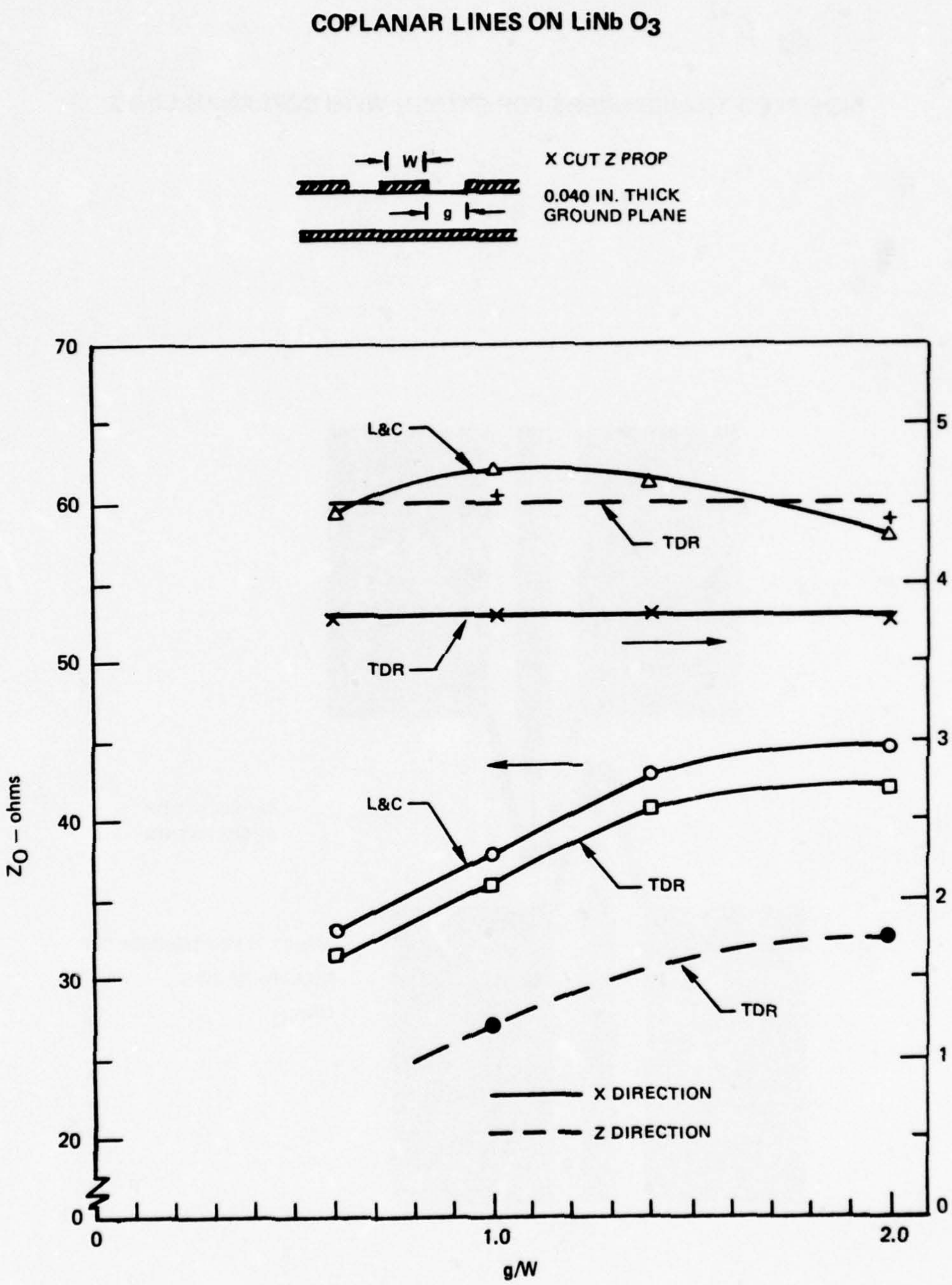
## 2.2 Delay Lines for the MLSO

The delay lines for the MLSO operating at 333 and particularly at 828 MHz are required to have relatively short delay times. Therefore, the transducer patterns which are in close proximity should be designed to minimize electromagnetic coupling. At higher frequencies the electromagnetic coupling is often enhanced if fine wire connections are made directly to the transducers. To reduce electromagnetic coupling, the transducer patterns were incorporated with coplanar transmission lines (Ref. 8) and grounded shielding bars were introduced between pairs of transducers. This permits locating the bonding wires as far as possible from the transducers so as to minimize radiation. In the GHz frequency range the lengths of coplanar lines begin to provide impedance conversion; however in this program the coplanar lines are still short enough to ignore the effect.

In conjuction with the transducer designs incorporating coplanar lines, coplanar transmission test lines were fabricated with different gap widths to obtain experimental data on characteristic impedance values and the electromagnetic velocity of propagation along the lines, Fig. 2. The coplanar transmission lines consist of a metallic strip on the surface of a substrate that is located symmetrically between two wider metallic strips on the same surface. The two wider strips serve as ground planes but also aid in shielding. This construction allows for control over the impedance of the lines joining the transducers and the usual 50 ohm lines used for interconnecting components. The coplanar lines were fabricated on substrates of $LiNbO_3$ that were 40 mils thick. Measurements were made both with and without a metal ground plane opposite the coplanar lines. It was found that the presence of a metallic ground plane was essential to minimize the electromagnetic coupling between the transducers. For gap widths between 1 and 2 times the center conductor width, the characteristic impedances were found to range between values of 30 and 40 ohms, Fig. 2. The width of the conducting strip was selected to be 25 mils. The electromagnetic velocity of the propagation was found to be approximately a quarter of the free space value, see Fig. 2. There were some differences between the propagation parallel to the X-axis and parallel to the Y-axis. The determination of $Z_o$ and the relative electromagnetic velocity employed both Time Domain Reflectometry (TDR) and measurements of inductance (L) and capacitance (C) per unit length over the frequency range of interest.

The design of a 333 MHz delay line using electromagnetic shielding bars and coplanar transmission lines is shown in Fig. 3 and the measured results are shown in Fig. 4. The coplanar transmission lines are oriented perpendicular to the direction of acoustical propagation in this configuration (side-feed), the coplanar lines are relatively short. The signal interference between the electromagnetic and the acoustic signals (less than 0.5 dB) indicates that the electromagnetic signal was reduced to a negligible quantity, approximately 30 dB below the acoustic signal. The delay line response taken over a wider range of frequencies, Fig. 5, shows the beginning of a broad response at 670 MHz. Reference will be made to

FIG. 2

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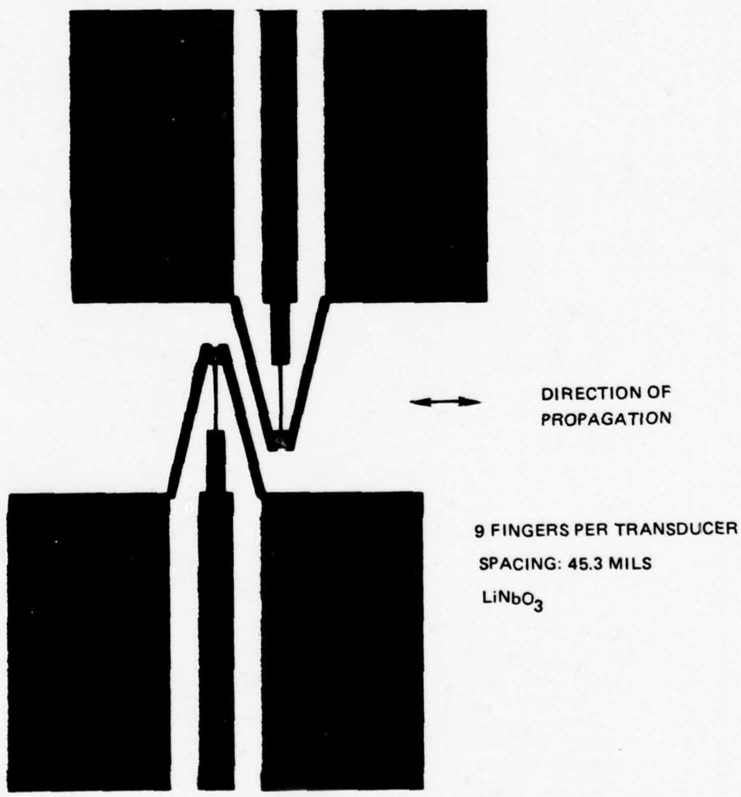
SIDE FEED TRANSDUCERS FOR 333 MHz WITH COPLANAR LINES

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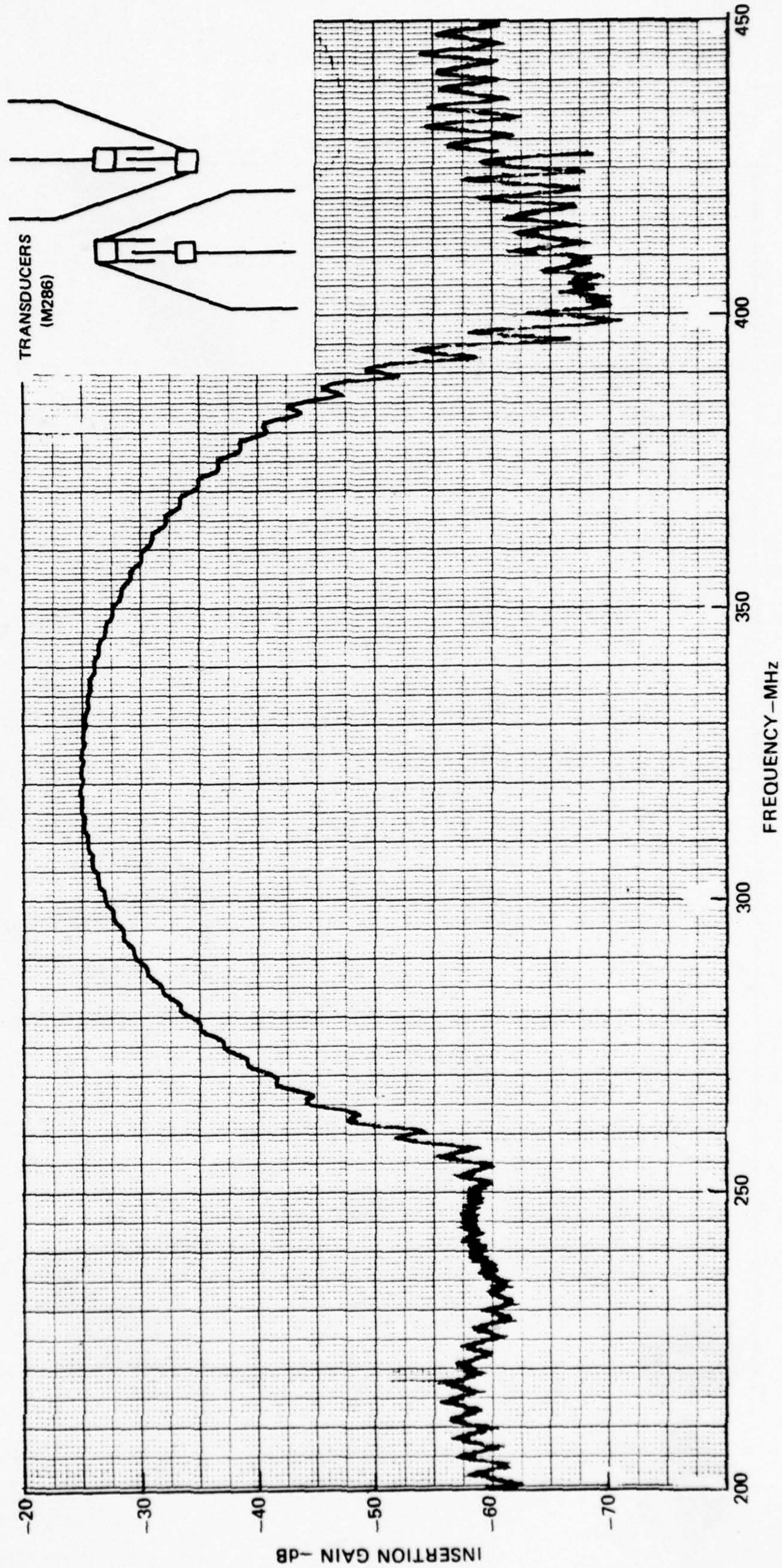
FREQUENCY RESPONSE OF SIDE-FEED CONFIGURATION AT 333 MHz



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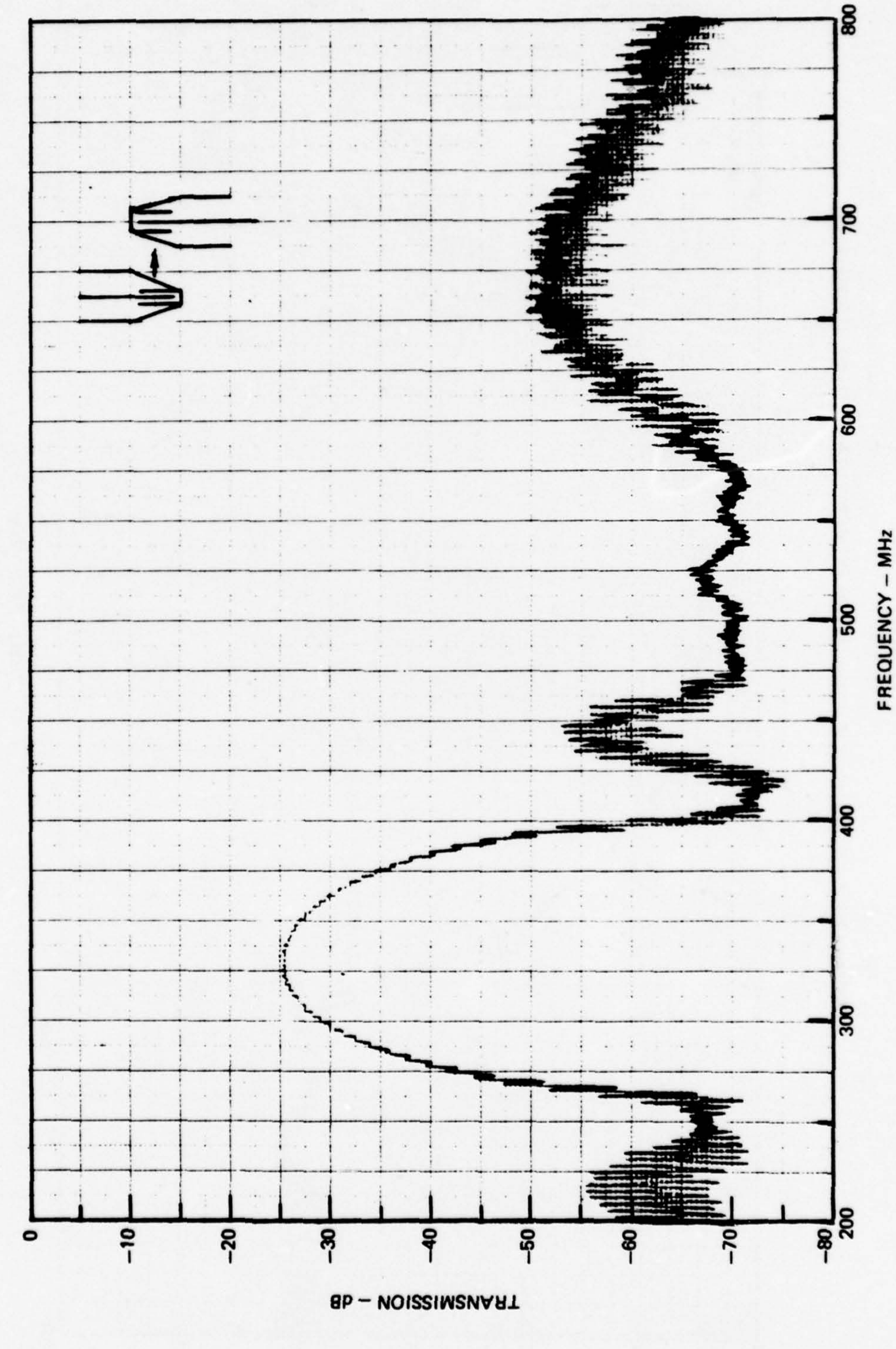
FREQUENCY RESPONSE OF 333 MHz SIDE–FEED DELAY LINE

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this response again in connection with the 828 MHz transducers. A second structure for 333 MHz was constructed in which the coplanar lines were oriented parallel to the direction of propagation (end-feed), Fig. 6. Two sets of measurements, Figs. 7 and 8, show the effects of electromagnetic coupling and the improvement gained from adding the grounded shielding bars. Finally, the third structure shown in Fig. 9 was fabricated and evaluated, again using the side feed. Its main purpose was to reduce the loss by a value of 3 dB by combining signals flowing in opposite directions from the driven transducer. The expected improvement was not realized; however, the out-of-band signal level was lower.

The design of the 828 MHz delay lines will be discussed next. Two configurations were considered, one an end-feed and the other a side feed. Since the comb spectrum at 828 MHz requires 30 percent bandwidth, broad banding techniques were required. For the end feed configuration the delay line consisted of two parallel acoustic paths tuned to different frequencies in order to give a broader response by means of stagger tuning. After a number of trial calculations with a computer model, a satisfactory design was obtained. The theoretical frequency response is shown in Fig. 10; the 1 dB bandwidth is 335 MHz. The specifications for fabricating the 828 MHz delay line on 41.5° Rotated Cut, X Propagation on $LiNbO_3$ are listed below:

| | | |
|---|---|---|
| Fingerwidths | 703 MHz | 1.5 um |
| | 952 MHz | 1.1 um |
| Transducer Spacing | (39.6 ns) | 158.4 um |

A computer program for generating photo mask patterns was available for this project. This program controls a machine which prints the entire transducer by means of a series of programmable rectangles. The general details of the 828 MHz delay line are shown in the computer generated plot of Fig. 11. The shaded areas represent the metallized regions. The faint rectangles seen through the shading represent the rectangles generated by the machine in printing the full transducer. In the transmission paths there are grounded electromagnetic shield bars. More details are shown in the enlarged views of the pertinent areas of the transducer. Figure 12 shows where the transducer and shield bars are located with respect to the connecting coplanar lines. In Fig. 12, the details of the transducer pattern itself are not evident. However, in Fig. 13 where the scales are further expanded, the actual interdigital fingers are seen. Note that the horizontal and vertical scales in Fig. 13 are different.

The $LiNbO_3$ substrate was mounted and precision polished on a block of stainless steel that is shown in Fig. 14. This block remains as a permanent part of the structure. This portion of the work was done at RADC including the projection printing of the transducers. The 10X masks were made at UTRC. The delay line fabrication at 828 MHz was done in two parts. The intricate portion of the delay line, the finger pattern, was done first. Then a second mask containing the coplanar lines was used to provide the terminals leading to the rest of the MLSO circuitry.

END FEED TRANSDUCERS FOR 333 MHz WITH COPLANAR LINES

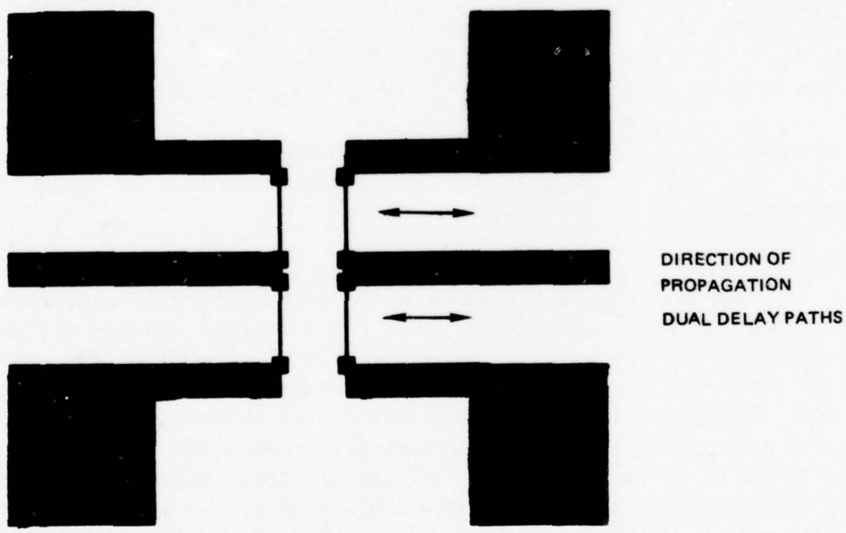


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FIG. 7

FREQUENCY RESPONSE OF 333 MHz END–FEED DELAY LINE WITHOUT GROUND BARS

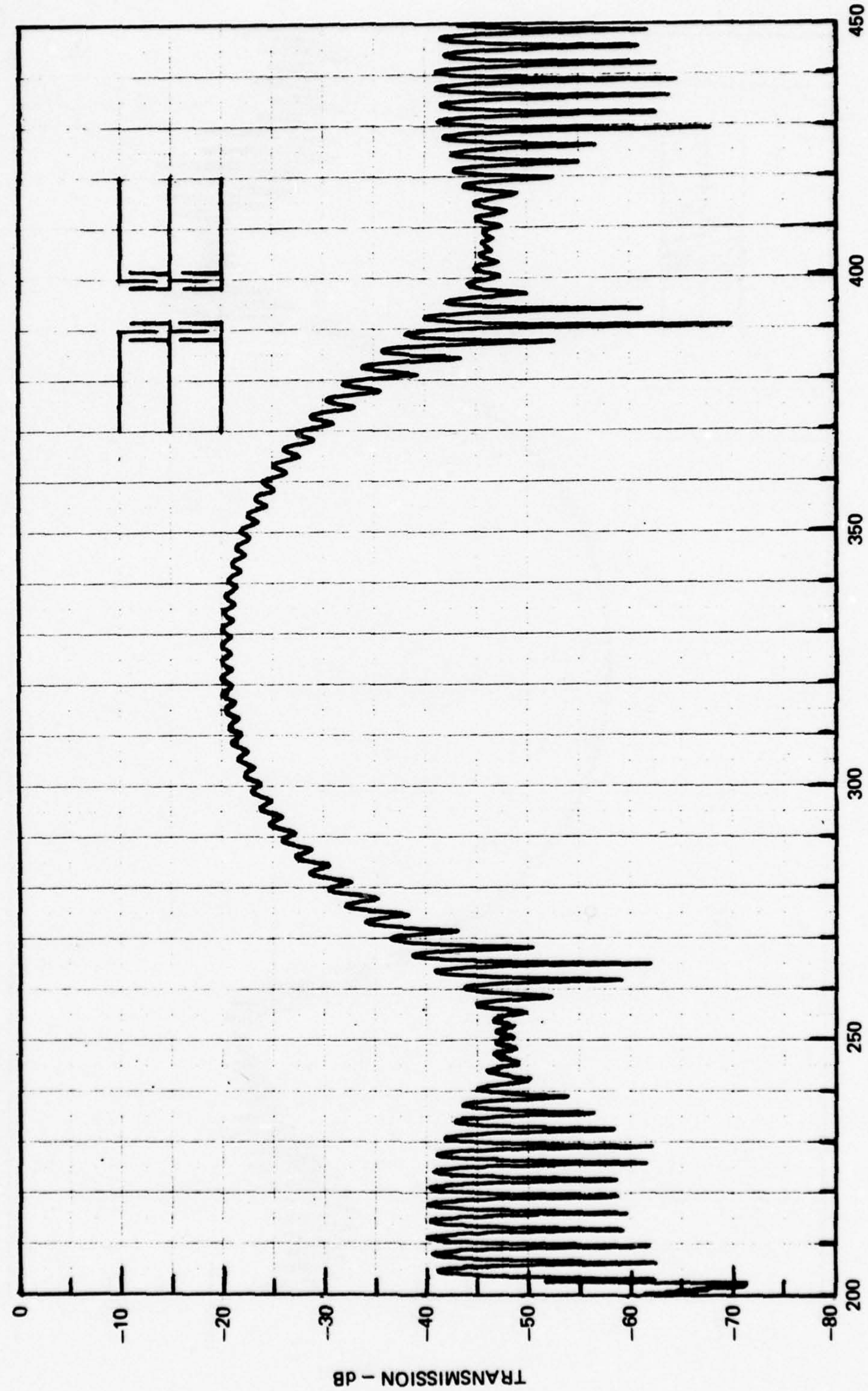


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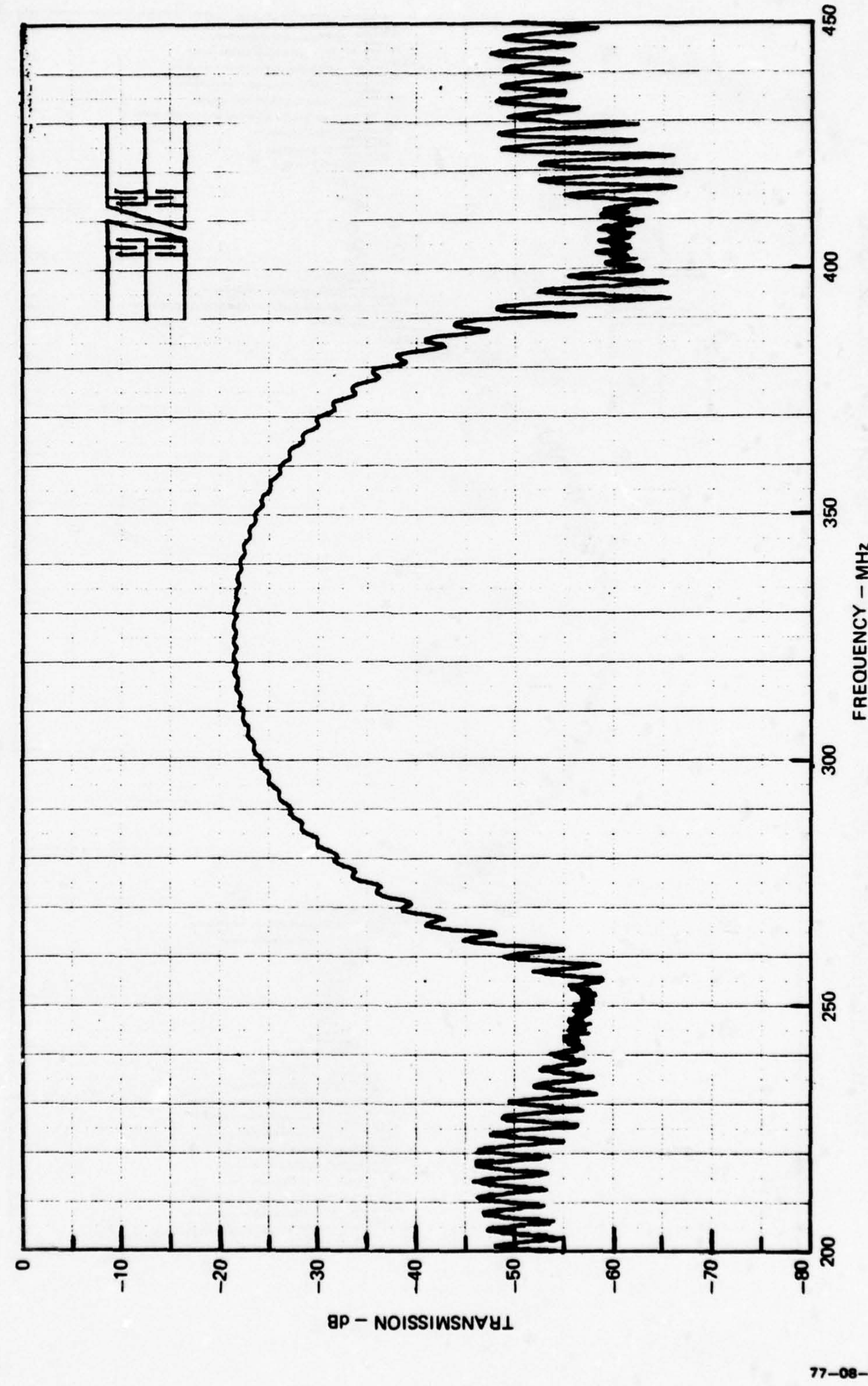
FIG. 8

FREQUENCY RESPONSE OF 333 MHz END-FEED DELAY LINE WITH GROUND BARS

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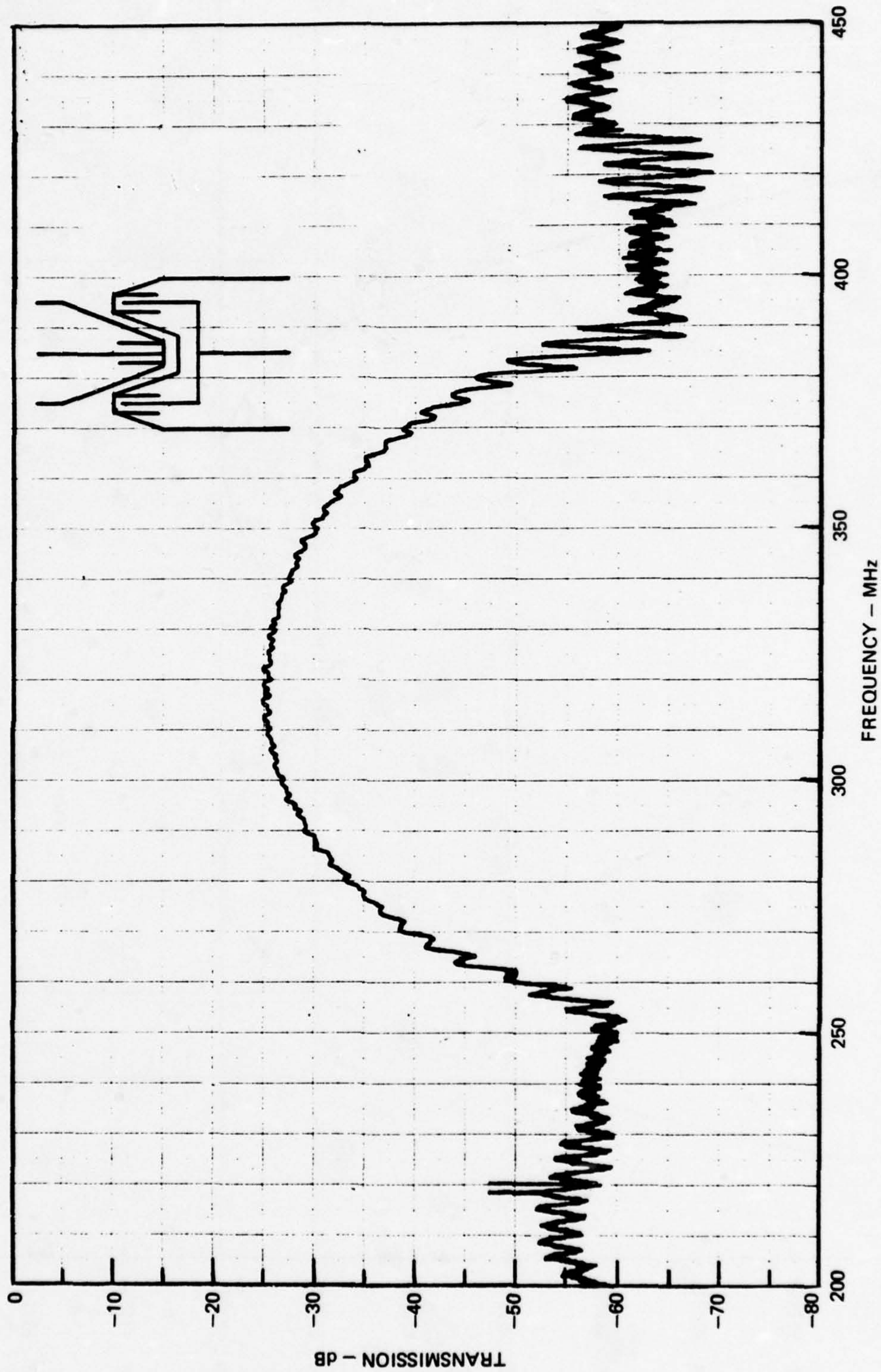
FREQUENCY RESPONSE OF 333 MHz 3 TRANSDUCER SIDE–FEED DELAY LINE

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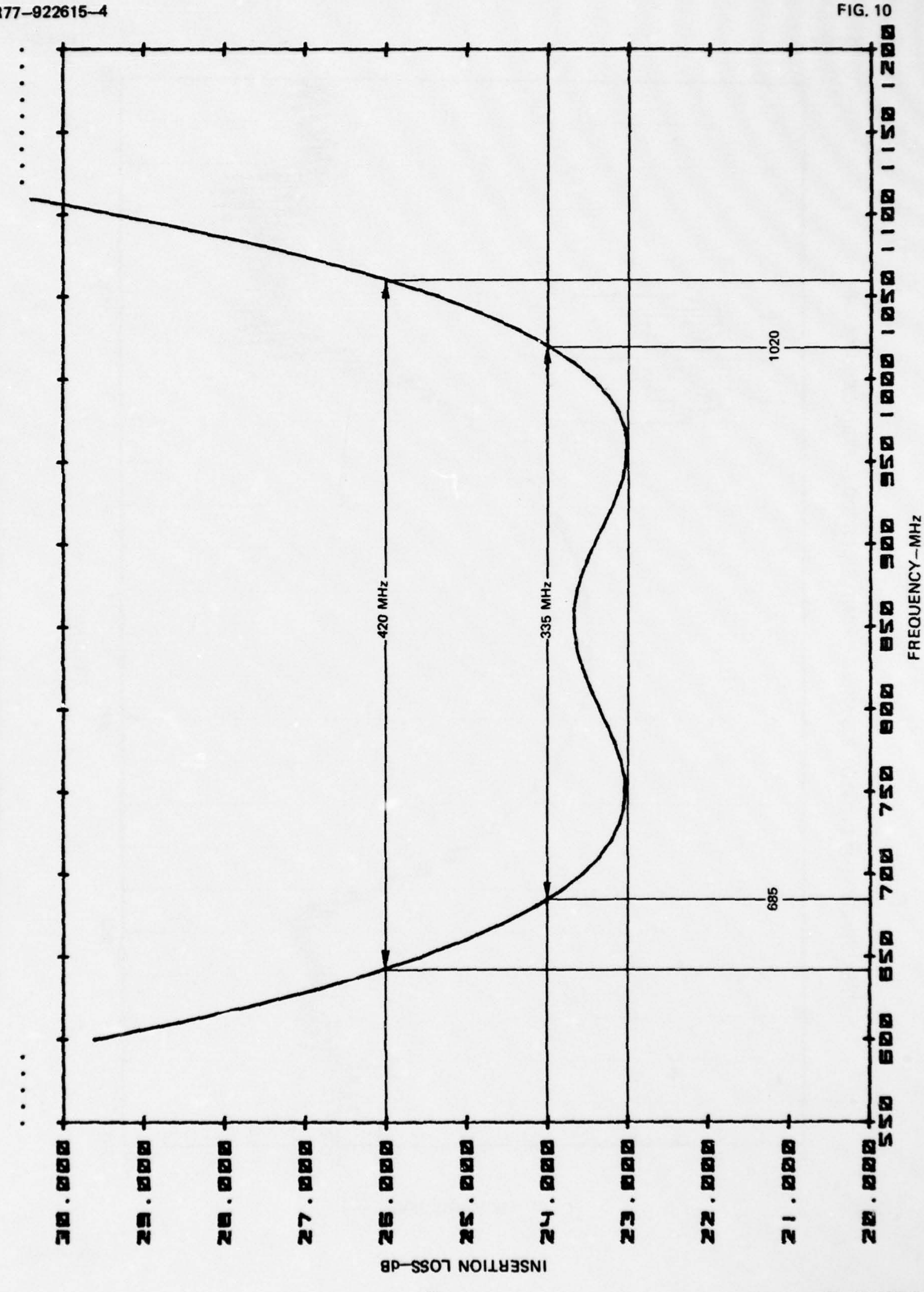
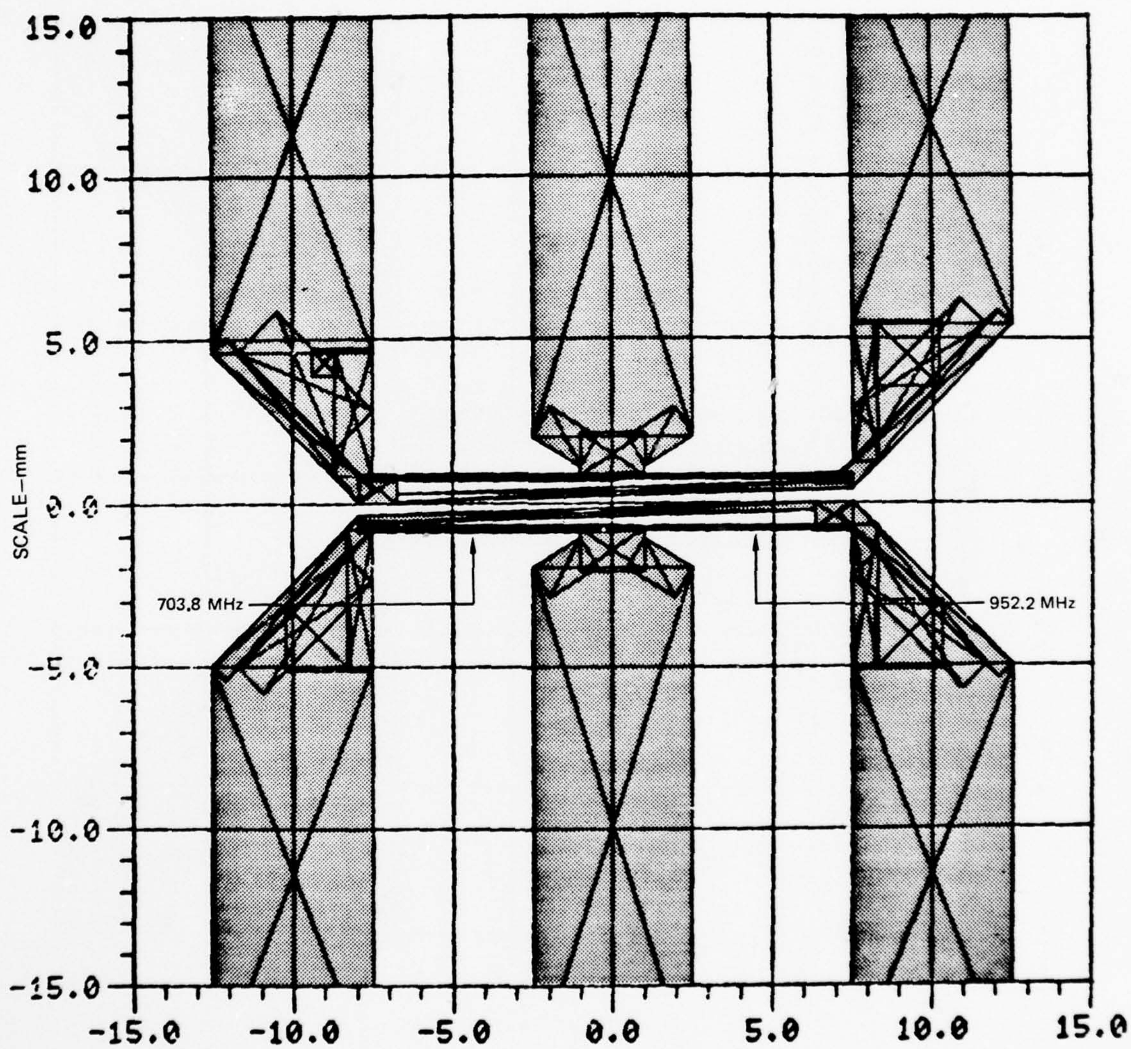
THEORETICAL FREQUENCY RESPONSE OF STAGGER TUNED TRANSDUCER



TRANSDUCER FOR 828 MHz

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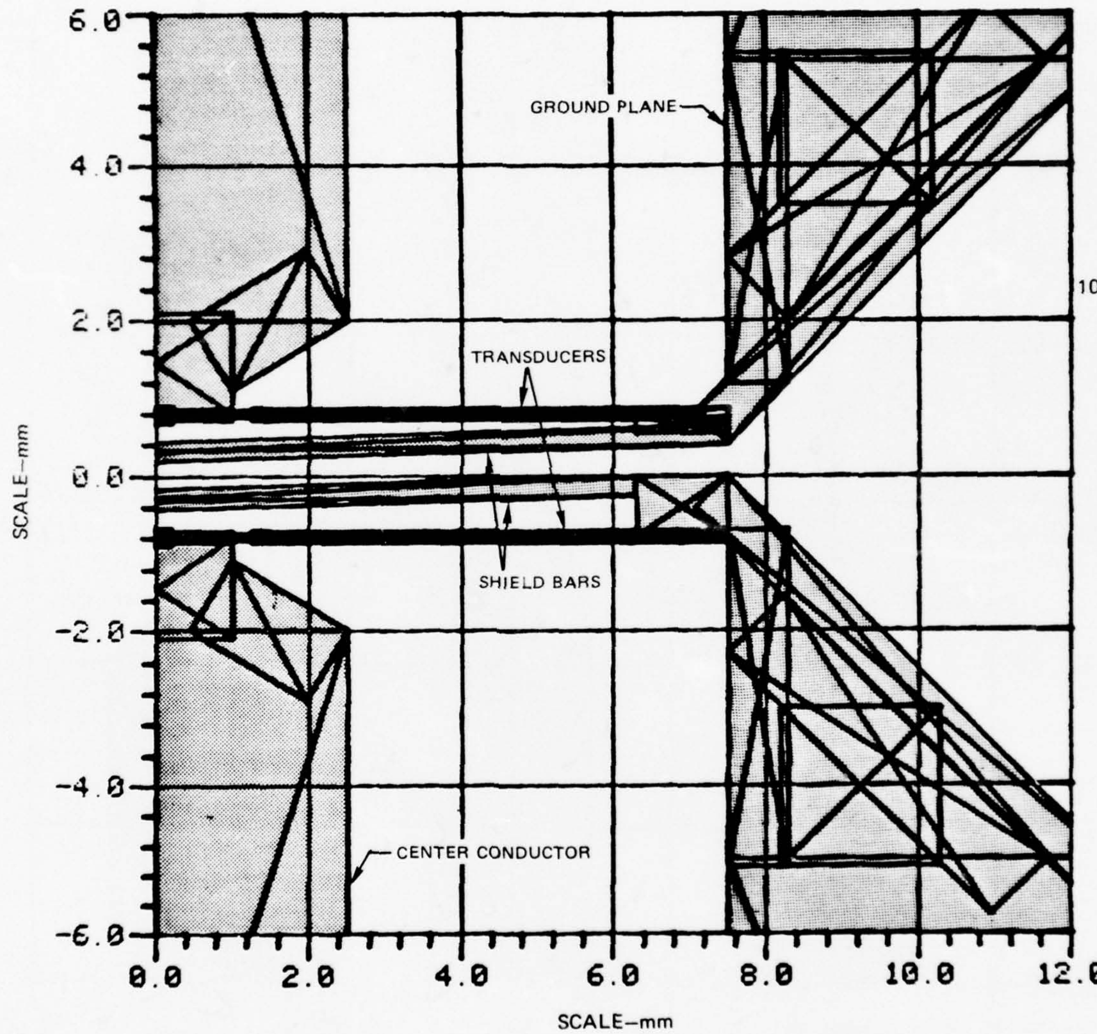
RIGHT HAND SECTION OF TRANSDUCER FOR 828 MHz

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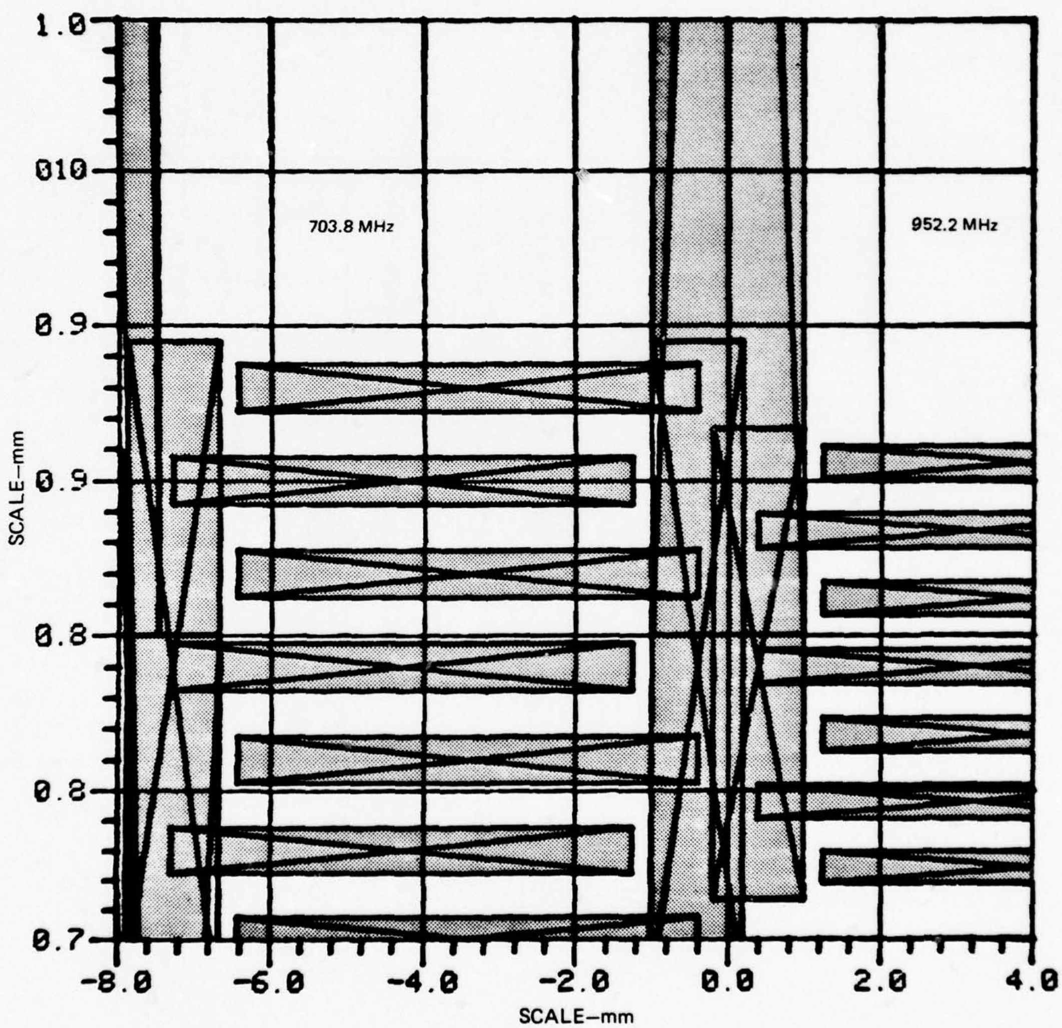
DETAILS OF FINGERS IN 828 MHz TRANSDUCER

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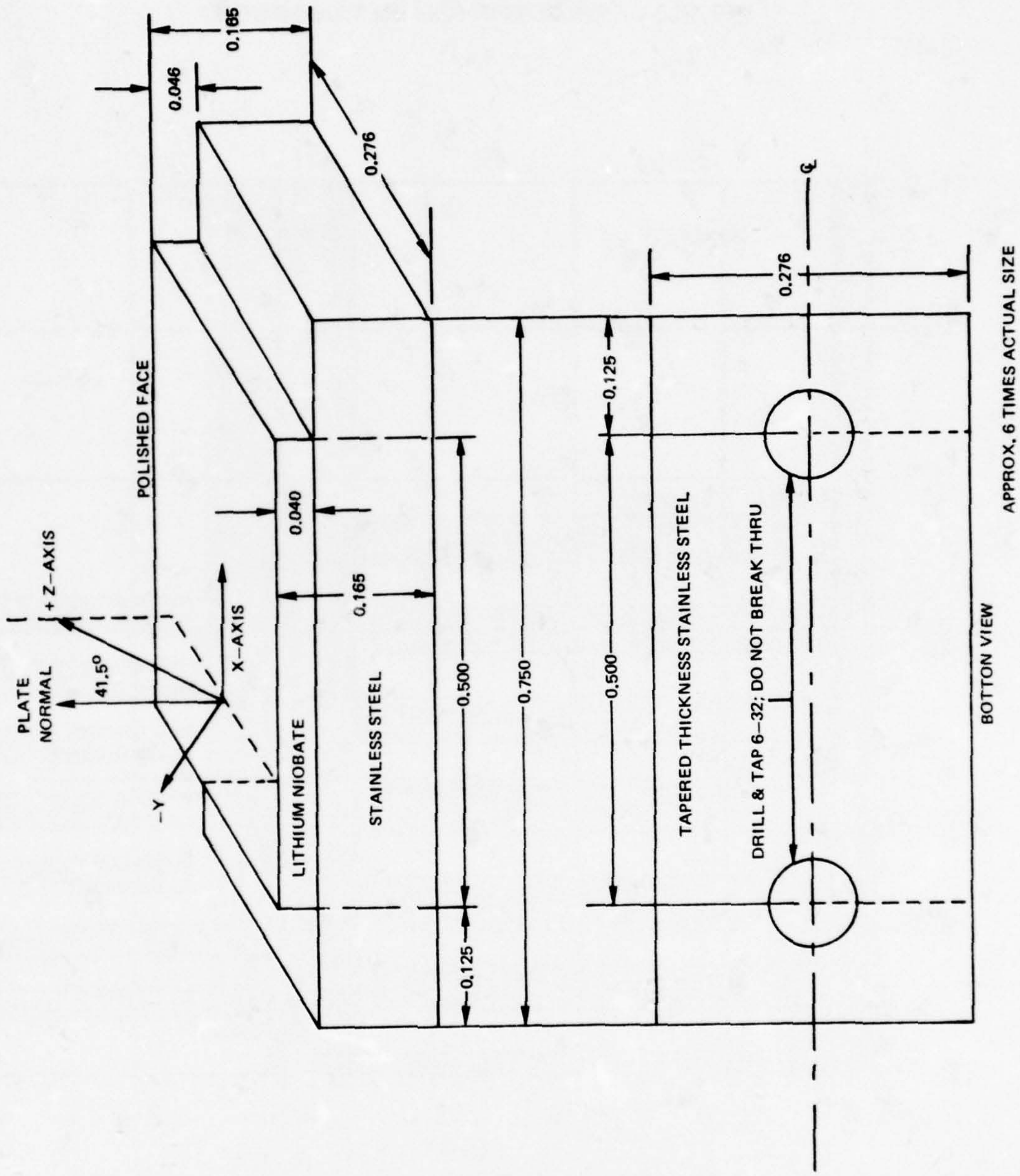
LITHIUM NIOBATE PLATES ON STAINLESS STEEL SLABS

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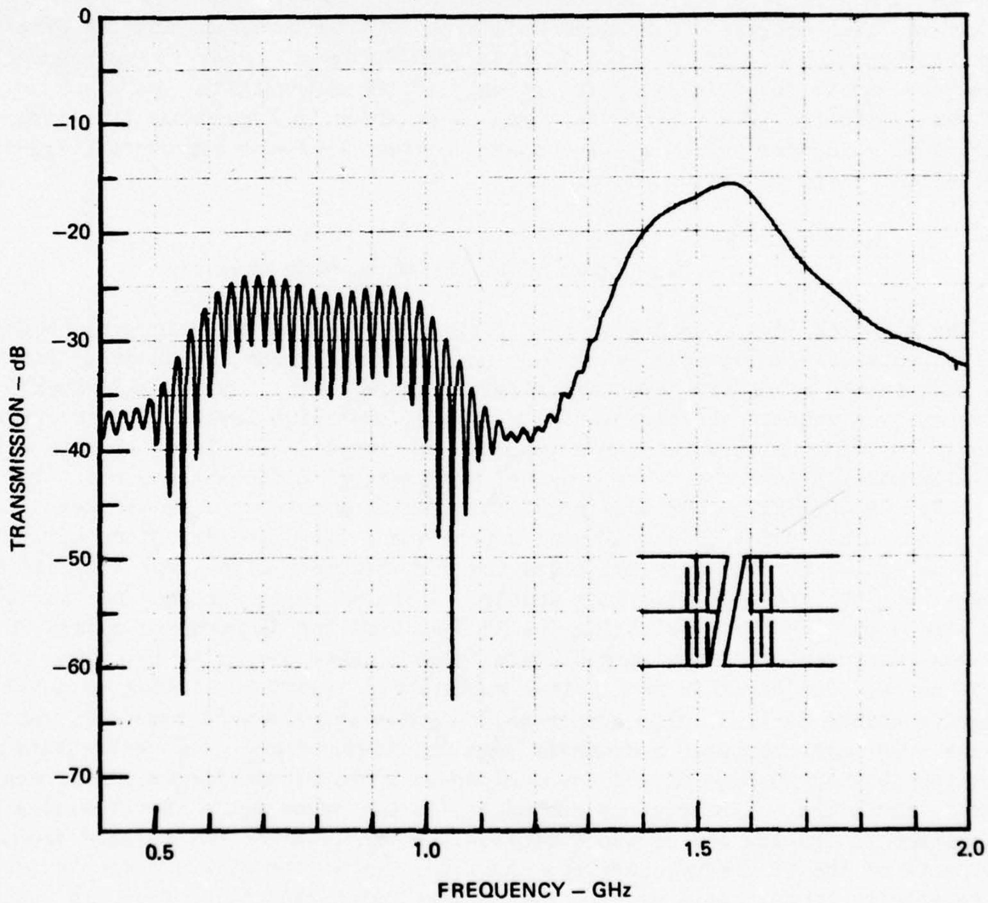
The frequency response of the end-feed delay line at 828 MHz is shown in Fig. 15. The broad band response is clearly evident; however, the high level of electromagnetic feedthrough is unacceptable as evidenced by the large depth of modulation in the frequency response. An interesting result is the second response, with very low loss, at about 1.6 GHz. A similar, but much lower level response was found in Fig. 5 for the 333 MHz transducer. These additional responses may be evidence of the bulk surface skimming waves (Ref. 9).

A second delay line design using the side feed transducers did have an acceptable low level of electromagnetic coupling as can be seen in Fig. 16. The additional response at approximately 1.6 GHz is seen again. This side feed transducer for 828 MHz was also designed to be generated by a computer program, and the details are shown in Figs. 17, 18, 19 and 20. In this transducer, in order to compensate for the added loss due to the relatively few fingers in the interdigital pattern, the delay line was fabricated with one central transducer which in turn feeds two transducers symmetrically located about it. The power received by these two transducers is combined and added in the output circuit.

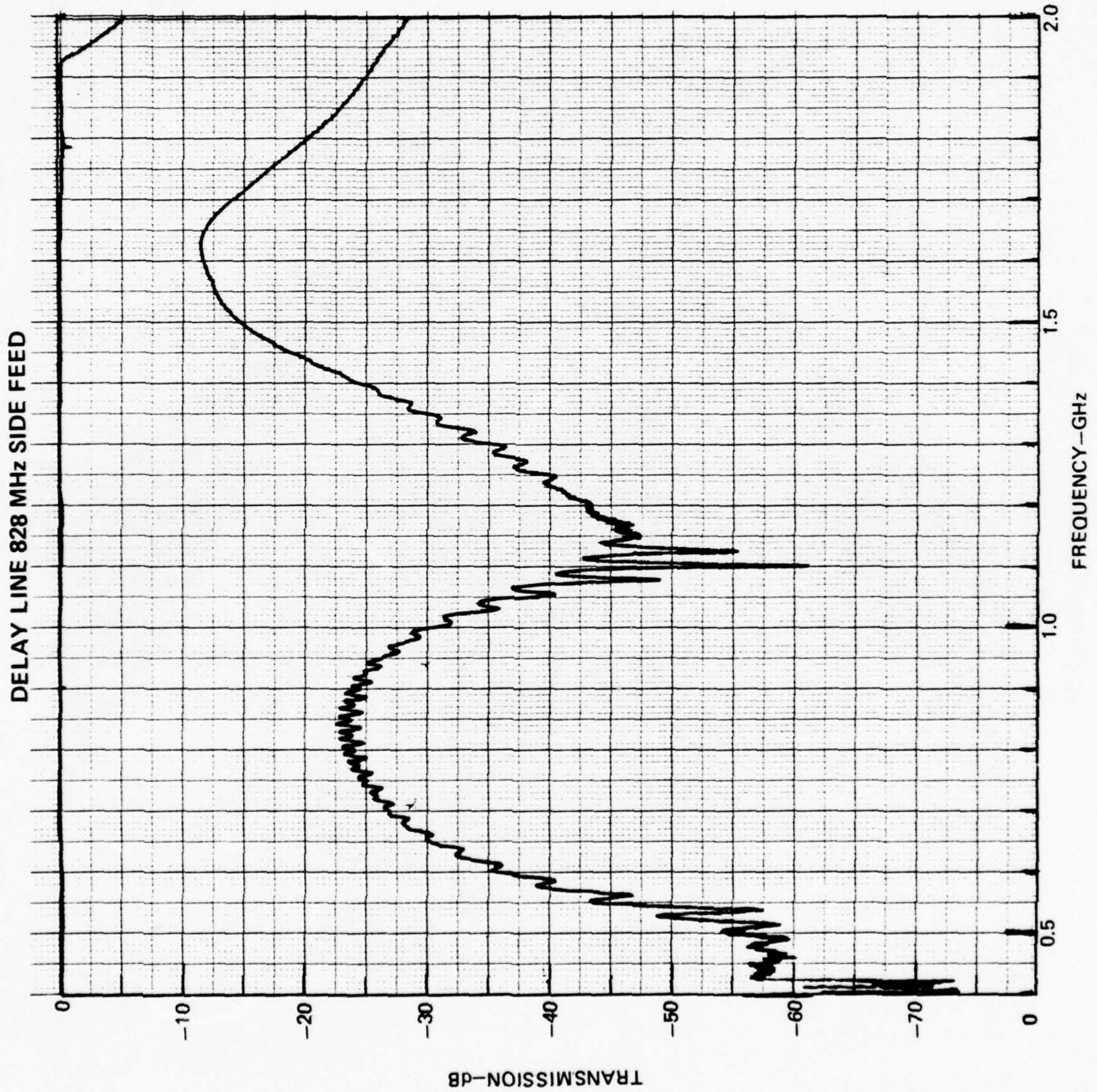
## 2.3 Experimental Results, MLSO Operation

The MLSO has been operated under a variety of conditions during the program in order to establish an optimum set. Some improvement, unique to SAW delay lines, was also made in the expander characteristics. With respect to subharmonic locking, at the repetition rate of the circulating rf pulse, excessive levels of noise were found in the comb spectrum at large input signal levels. The input signals were generally short pulses that were provided from several different sources. One source was an Avtech (AVS-S) pulser that provided nanosecond pulses, a second was a Chronetics pulser (PG-12), and a third source was a step recovery diode circuit The latter pulse forming network, using the step recovery diode, was intended for integration into the comb generator module. Although injection locking bandwidths that were equivalent to stabilizing the 333 MHz MLSO for temperature ranges of about 10°C were measured, the input signal level became large enough to introduce undesirable excess noise. One possible reason that subharmonic injection locking resulted in excessive noise, is that large synchronizing pulse signals were required, basically, because only high frequency components were utilized. These components caused injection locking through direct interaction with the rf components of the comb signal. Therefore, since most of the energy in the subharmonic synchronizing pulses is confined to the low end of the frequency spectrum, sufficiently large signal components at the rf frequencies were obtained only if the output from the pulser was relatively large. As a result, the residual wide band noise from the pulser is raised to levels large enough to appear in the output of the MLSO comb generator.

FREQUENCY RESPONSE OF 828 MHz END–FEED DELAY LINE



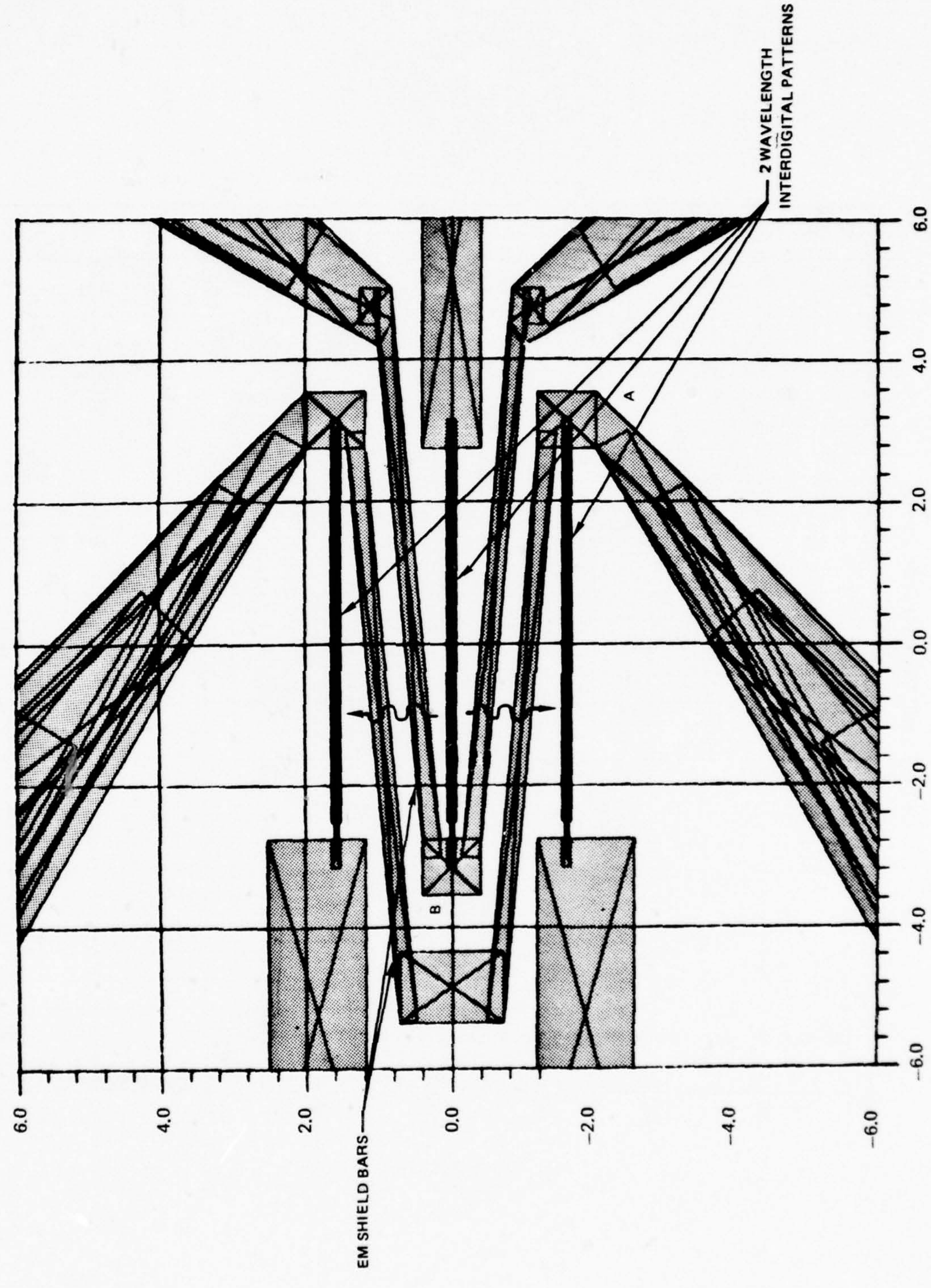

77–08–200–5


DELAY LINE 828 MHz SIDE FEED
0
–10
–20
–30
–40
–50
–60
–70
TRANSMISSION–dB
0
0.5
1.0
1.5
2.0
FREQUENCY–GHz

77–05–229–2

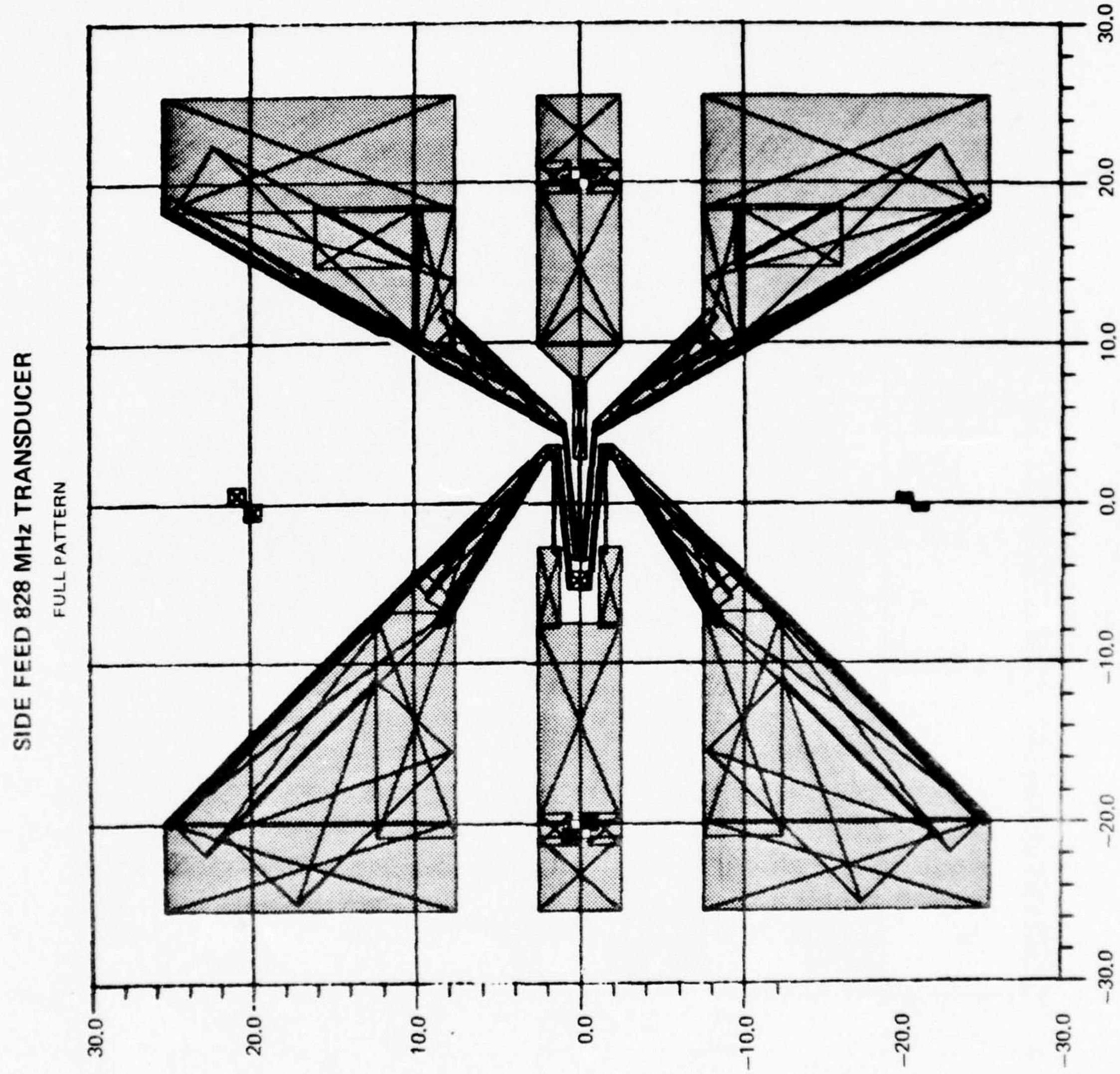
# SIDE FEED 828 MHz TRANSDUCER

CENTRAL SECTION



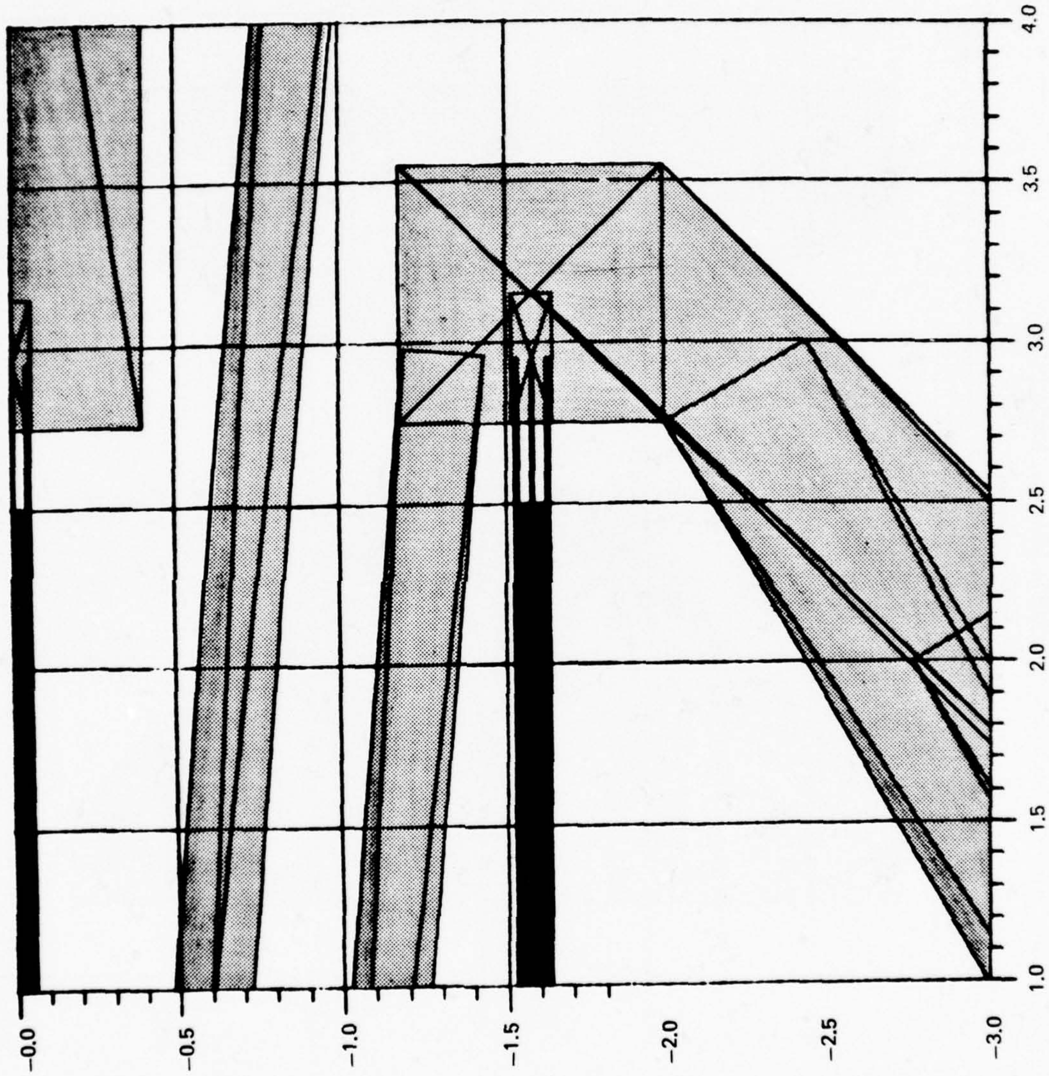

77–03–39–5

FIG. 18




77–03–39–6

FIG. 19



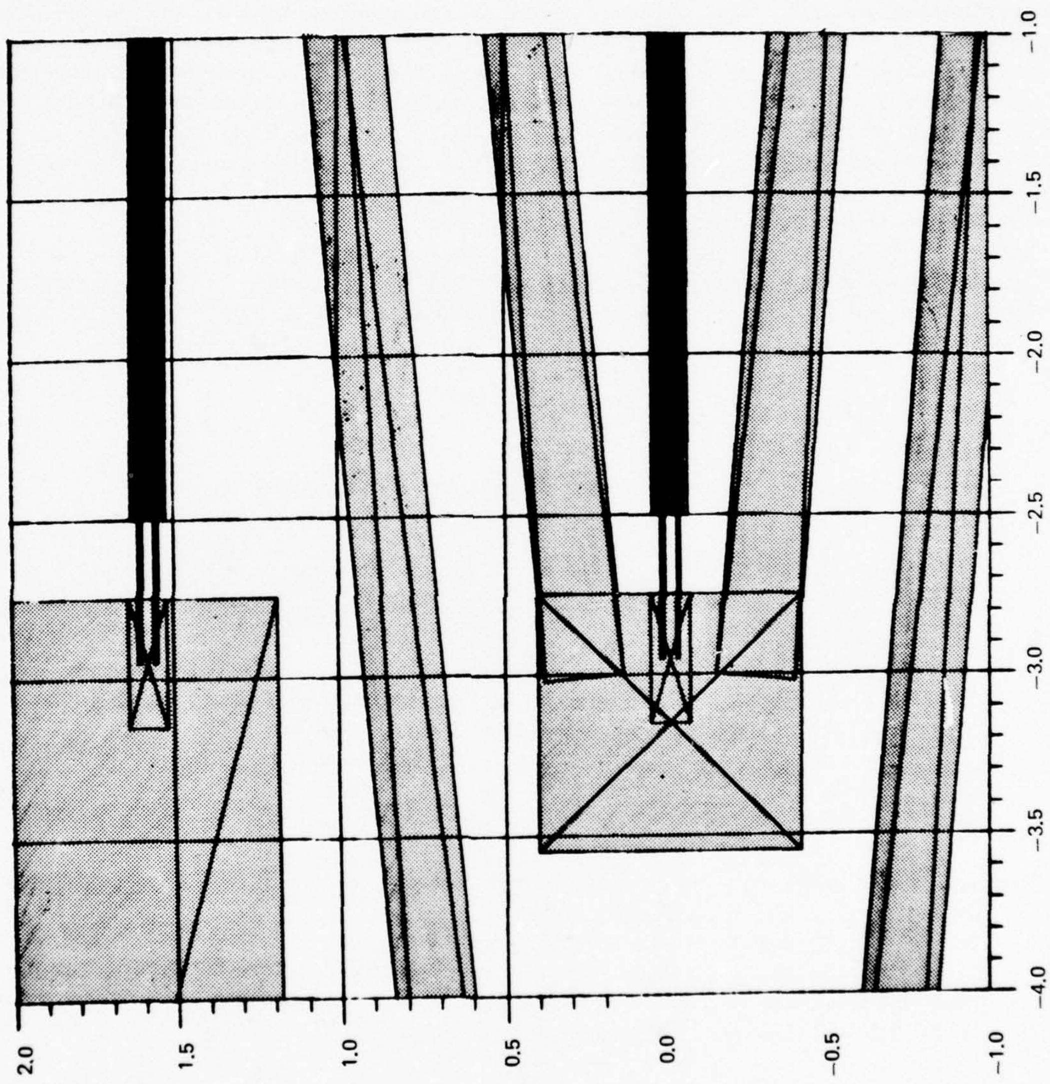

SIDE FEED 828 MHz TRANSDUCER

EXPANDED VIEW A

77–03–39–1

SIDE FEED 828 MHz TRANSDUCER

EXPANDED VIEW B




77–03–39–8

An alternative injection locking technique can make use of a CW fundamental frequency signal. This signal at the carrier frequency automatically forces the rf pulse repetition rate to be an exact subharmonic of the rf frequency. Preliminary experimental results, thus obtained, were so encouraging that it was decided to proceed with fundamental locking for developing the comb spectrum generator sources. In these experiments the MLSO was operating at the 333 MHz center frequency and the injected CW signal from a laboratory signal generator was introduced through a directional coupler. The coupler was located in the MLSO loop at a point where the signal level was lowest; therefore, only a low level injected signal was required. Nine lines of the comb spectrum are displayed in Fig. 21 to form a composite of several spectrum analyzer photographs. The base line noise is equivalent to a -105 dBc/Hz and it is mainly residual noise of the analyzer. Taking the results of Fig. 21 and other spectrum analyzer results not included here, noise and spurious signal characteristics were obtained as tabulated in Table I:

TABLE I

NOISE CHARACTERISTICS WITH FUNDAMENTAL INJECTION LOCKING*

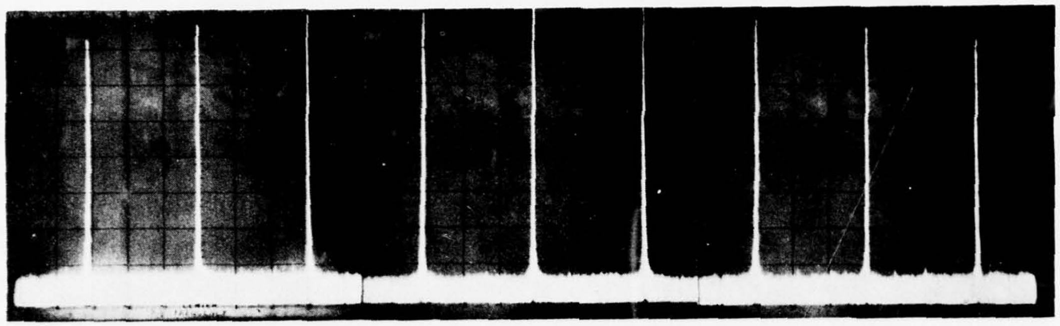
| Specifications | Experimental Results |
|---|---|
| FM noise requirement for low frequency comb: | |
| Less than -64 dBc/Hz ± 1 kHz from any tone - - - - - - | <-60 dBc/Hz |
| Less than -84 dBc/Hz ± 10 kHz from any tone - - - - - | -90 dBc/Hz |
| Less than -95 dBc/Hz ± 40 kHz from any tone - - - - - | 95 dBc/Hz |
| Less than -97 dBc/Hz ± 100 kHz from any tone - - - - - | -100 dBc/Hz |
| Less than -108 dBc/Hz ± 1 MHz from any tone - - - - - | <-105 dBc/Hz |
| Less than -108 dBc/Hz ± 1.5 MHz from any tone - - - - | <-105 dBc/Hz |
| Spurious requirement for low frequency comb: | |
| Less than -22 dBc ± 10 kHz from any tone | |
| Less than -32 dBc ± 40 kHz from any tone | |
| Less than -34 dBc ± 100 kHz from any tone - - - - - | All better than specifications |
| Less than -44 dBc ± 1 MHz from any tone | |
| Less than -47 dBc ± 1.5 MHz from any tone | |

*Measured with commercial oscillator

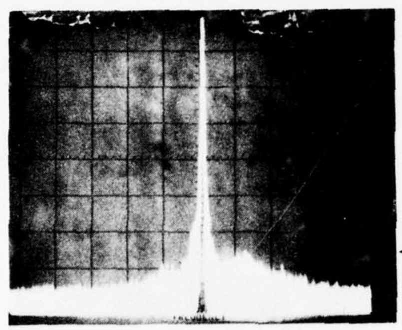
FIG. 21

77–03–97–2

SPECTRUM OF INJECTION LOCKED MLSO AT FUNDAMENTAL FREQUENCY, 333 MHz



1 KHz BW, 1 MHz/DIV, BASELINE – 105 dBC/Hz*



← –95 dBC/Hz

1 KHz BW, 50 KHz/DIV

VERTICAL SCALE 10dB/div

*ANALYZER LIMITED

The noise characteristics essentially meet the specifications over the entire range and the spurious characteristics also more than meet the specifications. However, as will be discussed in Section 3.0, the techniques to be used for generating the stable rf locking signal will result in low level spurious signals. With the judicious use of the unique properties of SAW comb rejection filters, these spurious signals are reduced to meet the requirements.

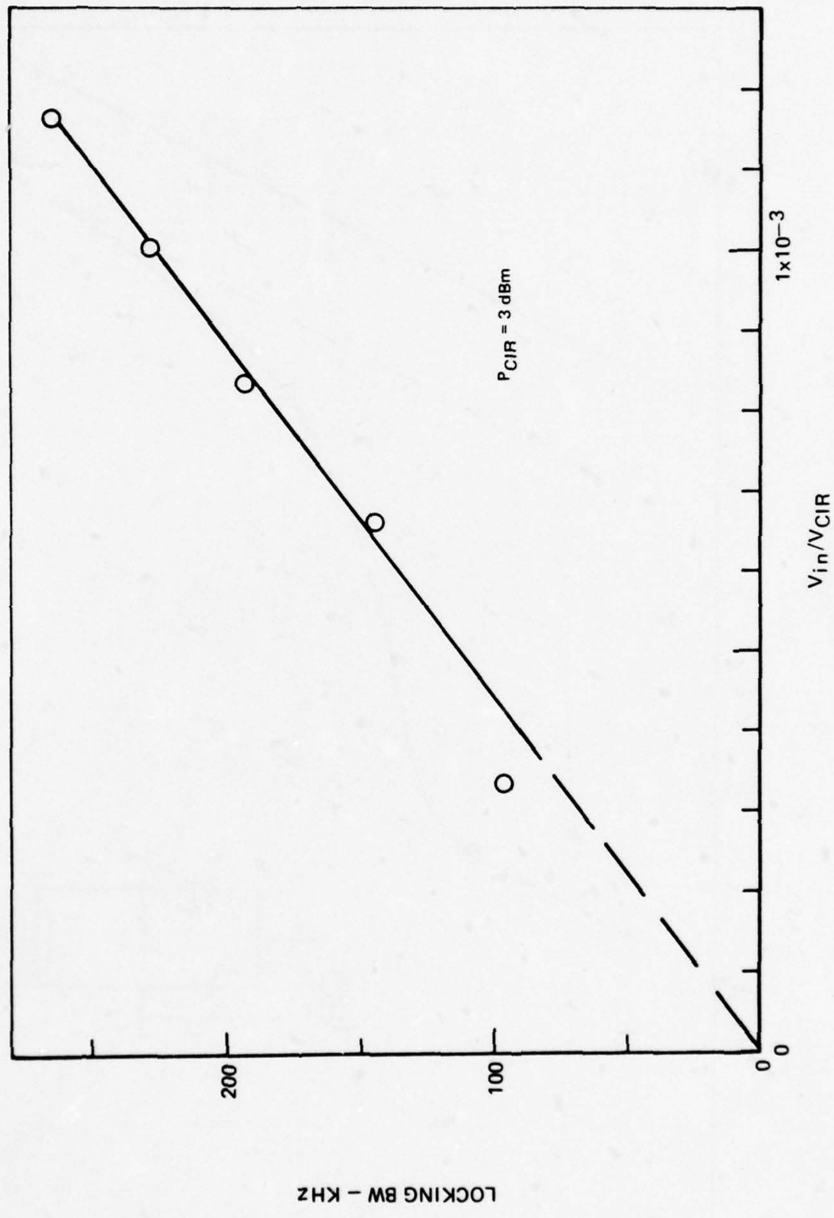
In any study of injection locking, it is useful to show how locking bandwidth depends upon the ratio of the input locking voltage to the voltage of the circulating signal. According to Adler's well-known theory on injection locking, the locking bandwidth should be a linear function of the voltage ratio. The results of such measurements for the 333 MHz comb generator are shown in Fig. 22 and, indeed, there is a good linear relationship. The slope of such a curve for CW conditions is the 3 dB bandwidth of the external resonant circuit. Further analysis of this point is required for rf pulse generators.

From the injection locking bandwidth an estimate can be made of the temperature range over which locking will be applicable. At the 333 MHz frequency, a locking bandwidth of about 200 kHz was obtained which corresponds to 600 parts per million. If we consider that $LiNbO_3$ has a temperature coefficient of about 100 parts per million, then this locking bandwidth would be adequate to stabilize the oscillator against temperature changes of approximately 6°C.

Expander circuits were discussed in Ref. 1 that included a simple voltage divider configuration and a bridge configuration using a transformer. An expander with improved performance was obtained by using a balanced type of configuration which is unique for SAW devices. The balanced circuit is obtained with rf signals applied to each end of the SAW transducer. The improved characteristics of this expander at 333 MHz is shown in Fig. 23. Included in Fig. 23 is a sketch of the balanced circuit; note that the nonlinear element is only in one arm of the balanced circuit. There is almost a 40 dB change in output when the input changes less than a 7 dB. Such a characteristic improves the ability to suppress noise in the interpulse time period and it also insures that a strong free-running capability is more easily obtainable.

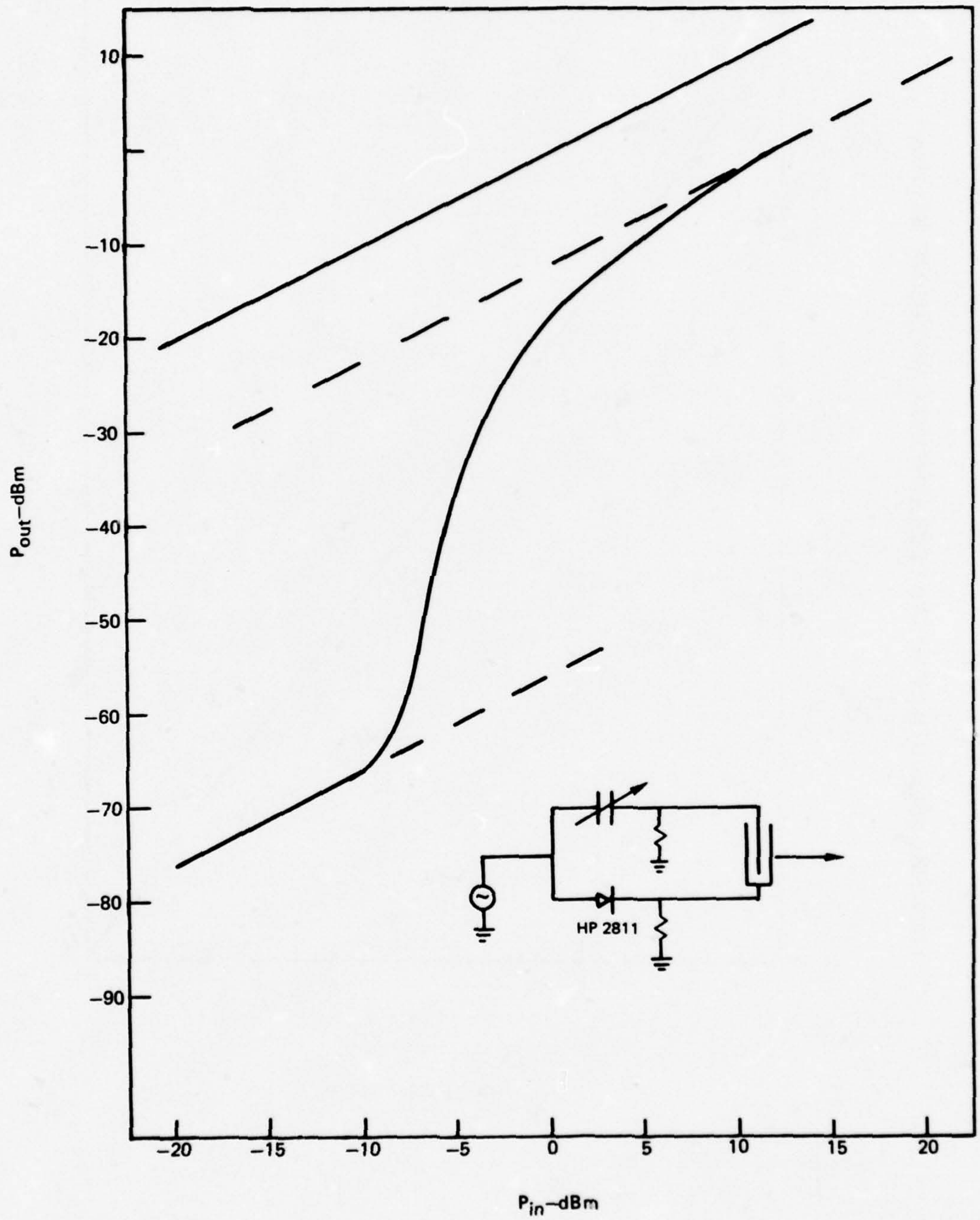
During the course of our experiments, an alternative set of conditions for mode locked operation were found that did not require the use of an expander, and furthermore, resulted in operation that was self-starting. The important component in this mode of operation was a transistor amplifier with its bias reduced to the point where no net gain was obtained. The operating voltage was about 4 volts where normally 24 volts would be used. At this level of bias the output of the amplifier was greatly distorted and sensitive to signal levels; however, the amplifier did not display any expander characteristics. On the other hand, the

LOCKING BANDWIDTH OF MLSO AT FUNDAMENTAL FREQUENCY, 333 MHz




77–03–119–1

## BALANCED EXPANDER RESPONSE AT 333 MHz

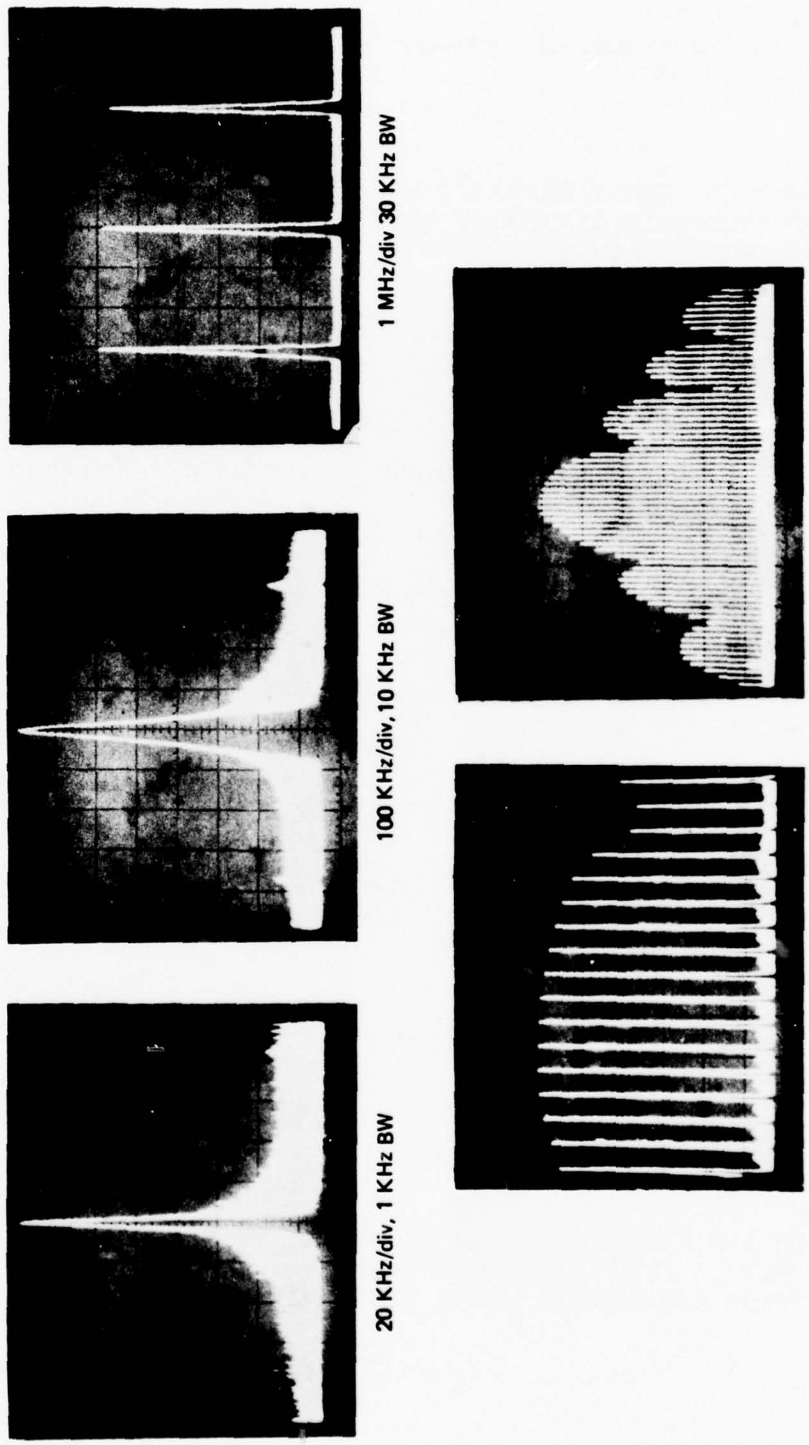



76–12–123–6

response of the amplifier to flat topped rf pulses showed an initial large amplitude followed by a decay in amplitude. This type of characteristic suggests that a form of relaxation oscillation was excited that was controlled by the SAW delay line. The comb spectrum generated while free running is shown in Fig. 24. The noise level between major lines is about -105 dB per Hz, at 20 kHz from the carrier it is -90 dB per Hz, and the spurious signal content is negligible. Injection locking at any one of the fundamental frequencies also takes place. This form of mode locked operation was also obtained at 828 MHz with the side feed delay line described in Section 2.2. The results at 828 MHz were obtained with a breadboard circuit that was not optimum; a full comb spectrum required for this program was not obtained.

FIG. 24

FREE RUNNING MLSO SIGNAL CHARACTERISTICS AT 333 MHz — COMB SPECTRUM



1 MHz/div 30 KHz BW

100 KHz/div, 10 KHz BW

20 KHz/div, 1 KHz BW

20 MHz/div, 100 KHz BW

5 MHz/div, 100 KHz BW

VERTICAL SCALE 10dB/div

# 3.0 STABILIZED COMB SPECTRUM GENERATOR

## 3.1 General Design

The design of the two stabilized comb generators and the 1984 single frequency source will be discussed next. In view of the results in the preceeding section on the MLSO it was advantageous to design the comb generators so that a low level CW signal is introduced into the MLSO feedback loop. This signal would be a reference signal at a frequency corresponding to a center line of the desired comb spectrum. The block diagram of the modified MLSO is that shown in Fig. 25. Miniature 10 dB directional couplers are used to introduce the injection locking signal and to extract the output signal. The expander is replaced by an amplifier operating at a reduced power supply voltage as was discussed in Section 2.3.

The CW injection locking signal for the MLSO must be derived from and synchronized with an external 1 MHz reference signal. For this purpose a practical technique that is now available makes use of a PLL (Phase Locked Loop) oscillator. For low noise considerations, operation of a PLL oscillator at as high a frequency as is practical is desired. Therefore, consider the factors in Table II of the ratios 333, 828, and 1984, which give the required output frequencies with respect to 1 MHz. Table II suggests choices of sets of frequencies, for the block diagrams outlined in Fig. 26, which could be used for the three signal sources. The columns labeled Factor contains the required frequency multiplication factors following the PLL oscillators. Three PLL oscillators generating a set of starting frequencies above 100 MHz appear to be most useful. The rf signals for injection locking and for generating the single line spectrum at 1984 are derived as follows: The 333 MHz MLSO requires that a PLL signal of 111 MHz CW signal be multiplied by a factor of 3, the 828 MHz comb spectrum requires that a PLL signal of 138 MHz be multiplied by 6 and the 1984 source requires that a PLL signal of 124 MHz be multiplied by 16.

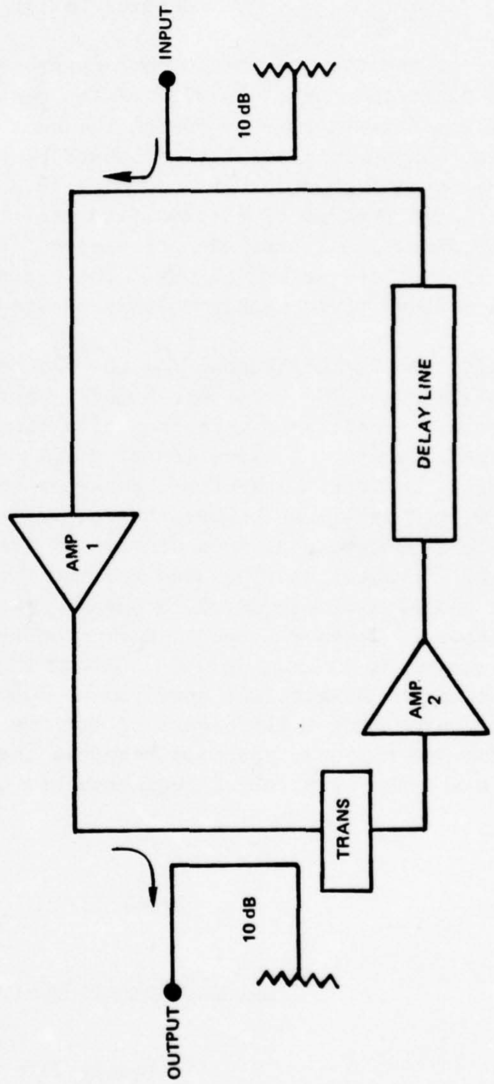
TABLE II

FREQUENCY RELATIONSHIPS

| Frequency MHz | Factors | Useful Sets of Starting Frequencies f MHz | Factor | f MHz | Factor |
|---|---|---|---|---|---|
| 333 | 37, $3^2$ | 37 | x 9 | 111 | x 3 |
| 828 | 23, $2^2$, $3^2$ | 46 | x18 | 138 | x 6 |
| 1984 | 31, $2^6$ | 31 | x64 | 124 | x16 |

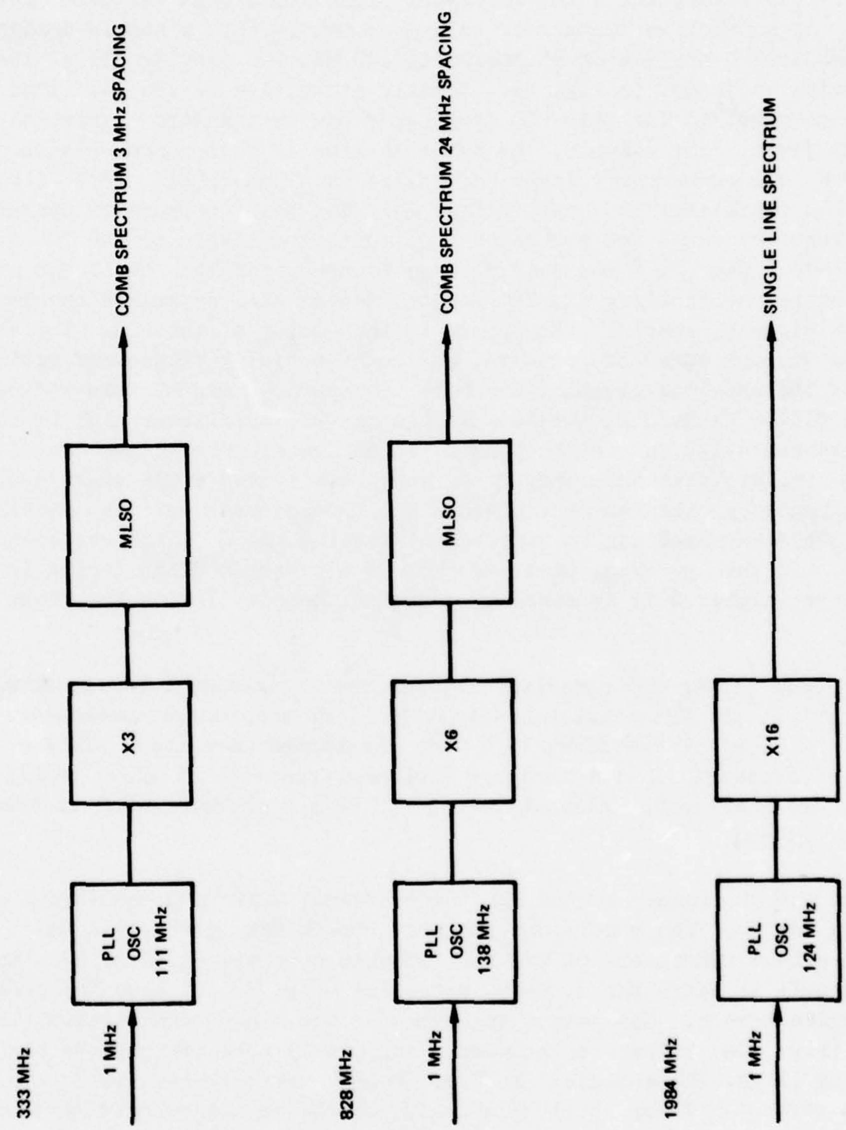
FIG. 25

FINAL VERSION OF MLSO




77-08-230-9

GENERAL BLOCK DIAGRAM SIGNAL FOR COMB GENERATOR PROGRAM




77–03–39–7

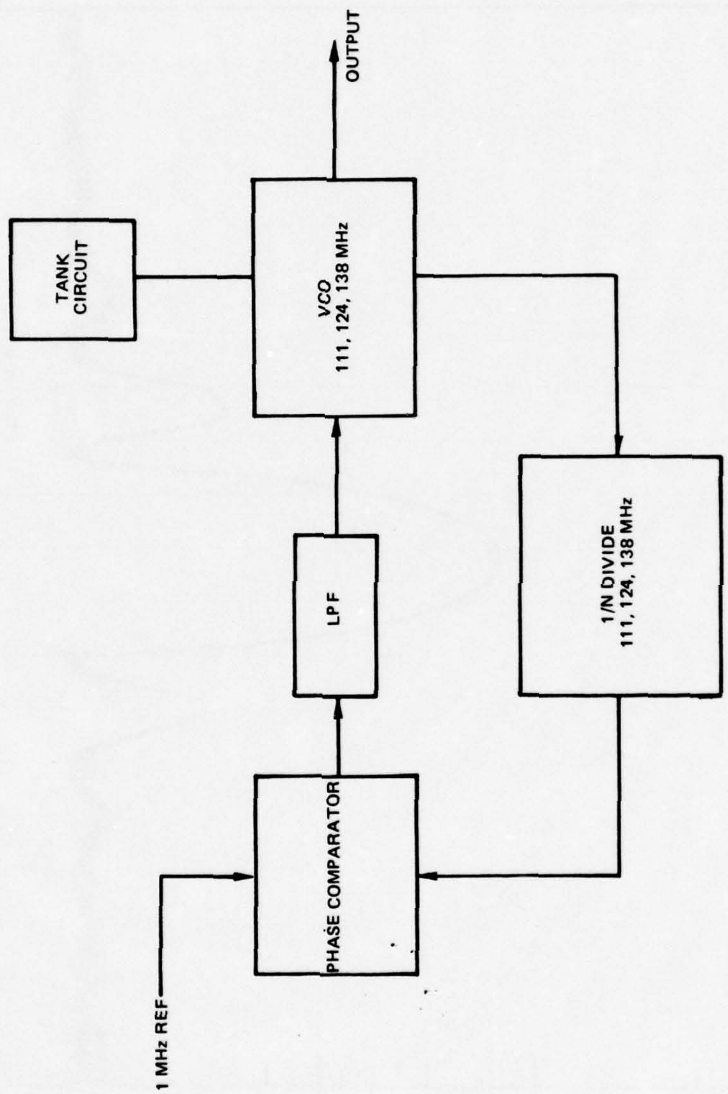
### 3.2 Phase Locked Loop (PLL) Oscillator

The Phase Locked Loop oscillator in the stable comb generator is the component used for translating the 1 MHz reference signal to a high frequency reference signal. An attractive feature of this approach is that a single design of a switch-programmable PPL oscillator at nominally 100 MHz can provide all of the starting frequencies indicated in Fig. 26. Equally attractive is the fact thal all of the components required for this PLL oscillator can be standard commercially available MIC components. For example, the Motorola line of MECL components can operate up to 200 MHz and includes a voltage controlled oscillator (Ref. 13). A block diagram of the PLL oscillator is shown in Fig. 27. The phase comparator operates in the 1 MHz frequency range and generates a dc control voltage for the VCO (voltage control oscillator). The LP, a low pass filter, is used to filter the 1 MHz signal from the dc signal controlling the VCO and its design will determine the level of the spurious signals, spaced 1 MHz apart, in the output of the VCO. The stability of the VCO, through speed of response, can be essentially traded-off against the level of the spurious signals; the more the spurious signals are reduced by narrowing the filter bandwidth, the less stable the PLL oscillator will be because of the increased delay in time response. In any case, through the use of post-filtering with SAW filters that have stop bands which are spaced 1 MHz apart around the PLL output frequency, the spurious signals are further reduced. The stability of the PLL on the other hand can be improved by raising the Q of the oscillator tank circuit. In this program, since wide-range electronic diode tuning is not required, the desired higher Q is obtained by reducing the coupling to the diode tuning element.

The SAW filter for removing the spurious signals at 1 MHz intervals around the PLL output at 111 MHz consists of two identical unapodized transducers on ST-X Quartz. A total of 448 double $\lambda/8$ wide electrodes were used. This corresponds to 111.5 wavelengths. The measured frequency response is shown in Fig. 28. Spurious signals are seen to be attenuated about 37 dB and the pass-band is free of any fine structure.

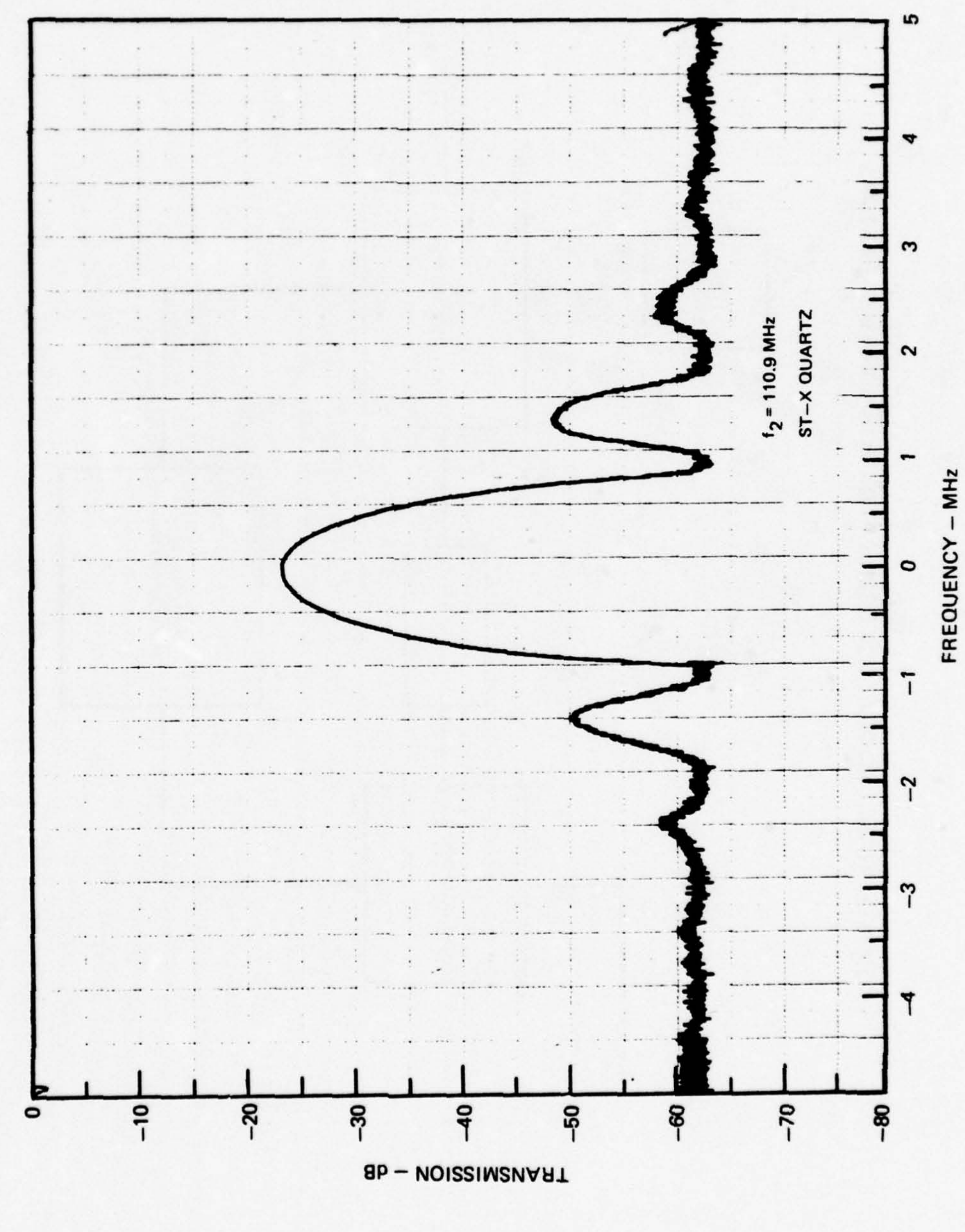
The output signals of the PLL under several different conditions are shown in Figs. 29 and 30. The conditions include a low Q tank circuit in which the tuning diode provides almost all of the tank circuit capacitance (Fig. 29a) and a high Q tank circuit in which the diode is decoupled (Fig. 29b). Note the large difference in FM noise levels. The output spectrum for the high Q case without the 111 MHz filter (Fig. 30a) is seen to be almost completely free of spurious signals after filtering (Figs. 30b and c). In Fig. 30 only two very low level (-75 dB) spurious signals persist. These spurious signals, which are not related to those mentioned above, are generated somewhere in the PLL oscillator but are small enough to ignore at this time. The tuning diode was decoupled by placing it in series with a fixed capacitor and then placing this series combination of elements in parallel with another fixed capacitor that served as the main tank circuit capacitor.

COMMON PHASE LOCKED LOOP OSCILLATOR FOR COMB GENERATORS



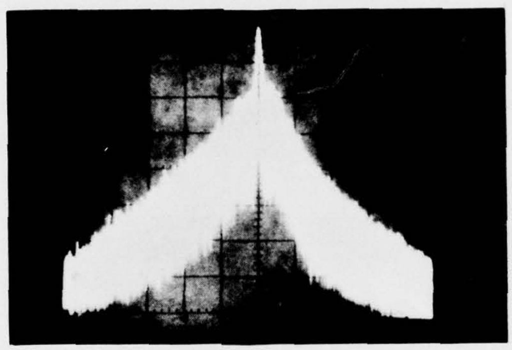

77–03–39–2

SAW FILTER AT 111 MHz

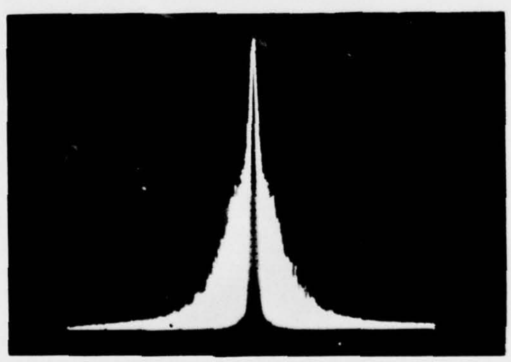



77–08–230–7

## PLL OSCILLATOR SPECTRUM



a) LOW Q PLL OSCILLATOR
WIDE TUNING



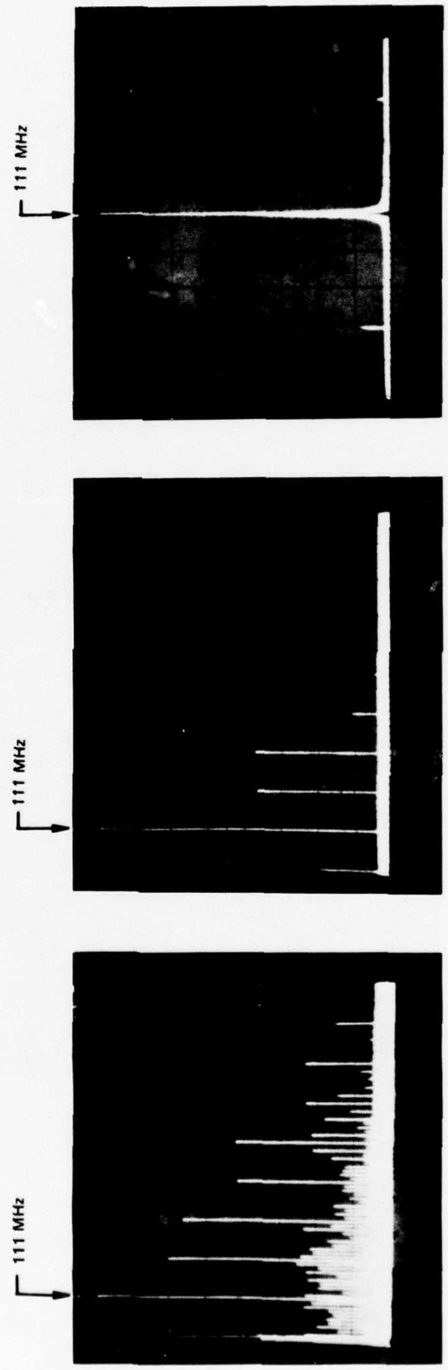
b) HIGH Q PLL OSCILLATOR
REDUCED TUNING RANGE

fo ≈ 111 MHz
20 KHz/DIV,1 KHz BW
VERTICAL SCALE 10dB/div

77–08–230–5

FIG. 30

## PLL OSCILLATOR OUTPUT SIGNAL




a) DIRECT, UNFILTERED
100 MHz/div, 300 KHz BW

b) FILTERED
100 MHz/div, 300 KHz BW

c) FILTERED
200 KHz/div, 1 KHz BW

VERTICAL SCALE 10dB/div



77–08–230–4

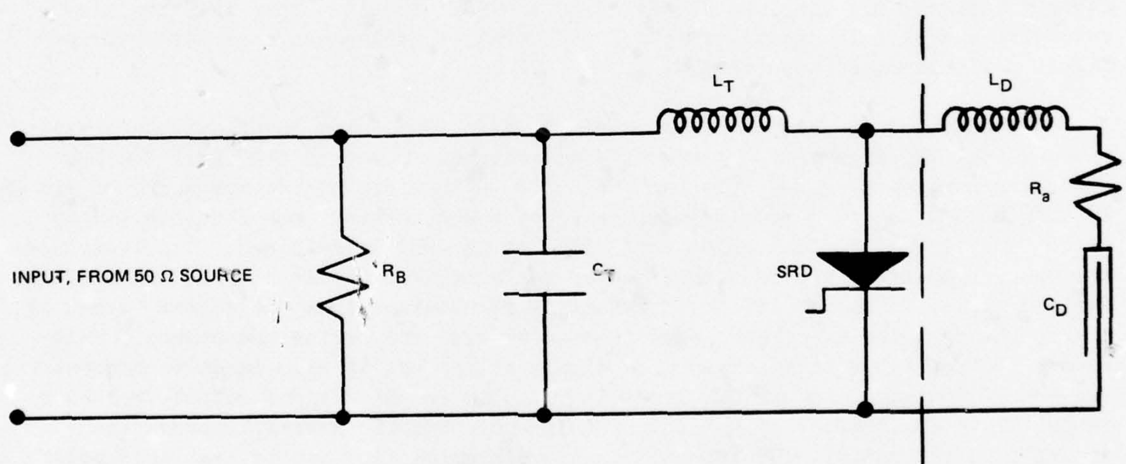
### 3.3 Frequency Tripler

One of the additional components for the two comb generator sources as discussed in Section 3.1 is a frequency tripler that is integrated with a SAW delay line filter. The SAW delay line filter provides filtering for the undesired harmonic signals. A SRD (Step Recovery Diode) frequency multiplier circuit capable of X3 operation with an input signal whose frequency is in the 100-150 MHz range was developed. The basic circuit including the SAW equivalent circuit components, Fig. 31, is similar to several described in the literature (10, 11, 12): but, since no attempt was made to impedance match to the 50 ohm driving source, the circuit is rather simple. The circuit includes the drive inductance ($L_T$), the high frequency (output frequency) bypass capacitor ($C_T$), a bias resistor ($R_B$) and a tuning inductor ($L_a$) for the SAW transducers. The bias resistor $R_B$ provides for self-bias operation of the SRD and thus no external dc power supply is necessary. The circuit shown is capable of driving a load impedance whose real part is greater than 40 ohms. The matching inductor used to impedance match the delay line load to the SRD output circuit insures that the load presented to the SRD circuit output is primarily resistive and also it greatly improves the signal-to-noise and signal-to-spurious signal performance of the circuit.

Operation of the circuit is summarized as follows. The input drive signal is a sinusoidal VHF signal at 111 MHz with an available power of +13 dBm. The SRD circuit generates a narrow pulse at the output with a repetition frequency of 111 MHz. The SAW delay line then provides filtering of the generated comb spectrum (lines spaced by 111 MHz) so that only the X3 line at 333 MHz is selected. The transducer response, by design, provides only one of the contributions to attenuating the undesired signal lines; additional attenuation is obtained from the filter formed by tuning the capacitance of the input transducer with the series inductance. This resonant circuit not only serves as a simple filter but it also tends to concentrate the energy contained in the SRD generated impulse in the desired output frequency range. This enhancement of the output frequency tends to greatly improve the signal to noise ratio. The output from the SAW delay line has an available power of -27 dBm. The quality of the circuit performance is illustrated by the series of spectrum analyzer photographs in Fig. 32. The noise characteristics more than meet the overall comb generator specifications and were obtained with a common laboratory signal generator as a driver. The main spurious harmonic signals in Fig. 32 are adequately reduced to levels 20 dB below the desired signal. The 333 MHz filter used for these results was identical to the delay line used for the MLSO.

A SAW filter for the frequency multiplier was designed to pass signals at 333 MHz, to reject other harmonics, and in addition to reject signals spaced at 1 MHz intervals from the desired signal at 333 MHz. In order to accomplish this one transducer of the SAW filter had 62 $\lambda/4$ electrodes at 333 MHz while the other had 448 $\lambda/8$ electrodes at 111 MHz. The first transducer produces nulls at approximately 11.1 MHz intervals around 333 MHz which would, in particular, reject 111,

MULTIPLIER, 111 TO 333 MHz




$L_T \sim 80$ nh

$C_T \sim 30$ pf

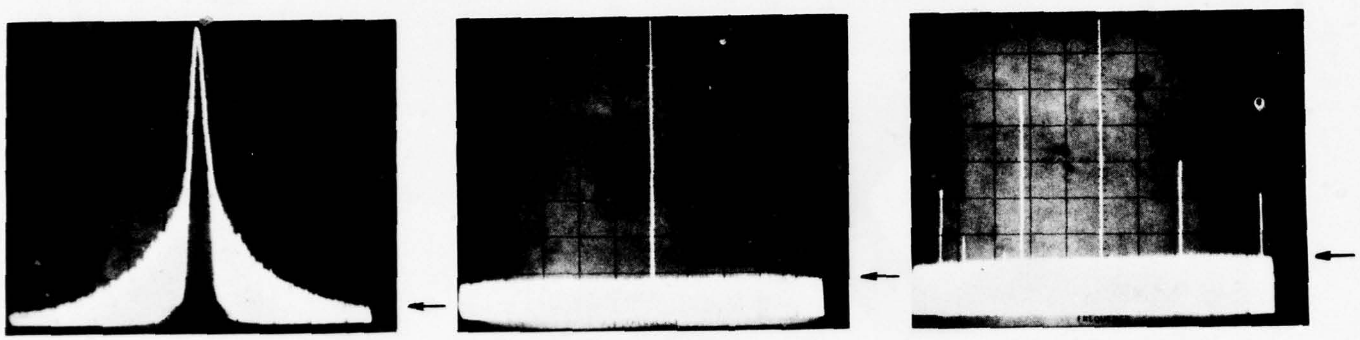
$R_B \sim 750\ \Omega$

SRD: H.P. 5082–0180

77–03–87–1

FIG. 32

**MULTIPLIER, X3, SPECTRUM AT 333 MHz**



1 KHz BW, 10 KHz/DIV
BASELINE -105 dBC
PER HERTZ

10 KHz BW, 5 MHz/DIV
BASELINE −110 dBC*
PER HERTZ

100 KHz BW, 50 MHz/DIV
BASELINE −115 dBC*
PER HERTZ

VERTICAL SCALE 10dB/div

*ANALYZER LIMITED

77–03–97–1

222, and 444 MHz signals. The second transducer at its 3rd harmonic would produce nulls at 1 MHz intervals around 333 MHz. The second transducer design was the same as that used for both input and output of the 111 MHz filter discussed earlier in Section 3.2. The response of this 333 MHz filter for the harmonic generator is shown in Fig. 33. The frequency response is centered slightly below the desired value; however, the smooth curves and well defined sidelobes indicates that this SAW filter is operating properly. The filter has no other responses from 100 to 600 MHz; however, the general level of transmission slowly rises to about -50 at 100 MHz and 500 MHz. A slight scaled decrease in transducer size should shift this filter response up to the required center frequency.

## 3.4 Final Design and Results for the 333 MHz Comb Stabilized Comb Generator

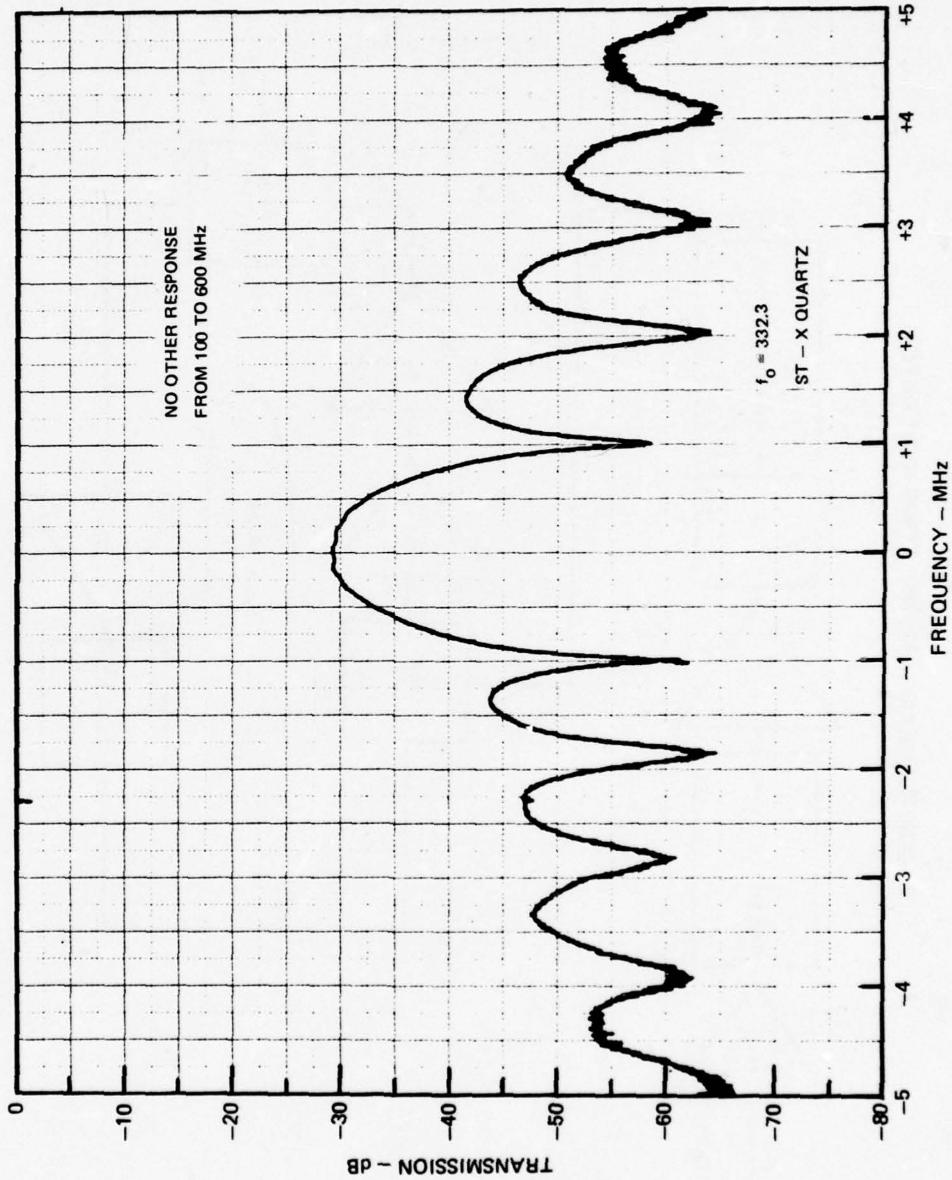
The final design of the stabilized comb spectrum generator driven from a PLL oscillator is shown in the block diagram of Fig. 34. The addition of a directional coupler allows a low level injected signal to be introduced. This signal is the filtered output of the frequency multiplier. The filter finally selected was the same as that used as the delay line in the MLSO; it suppressed the unwanted harmonics such that they are more than 20 dB below the desired signal as shown in Fig. 32. The filter preceding the frequency multiplier effectively suppressed the low level spurious signals from the PLL oscillator as was shown in Fig. 30. These two filters gave better results than were obtained using the single filter described in Section 3.3. Prefiltering of the PLL oscillator output was essential.

The complete stabilized comb generator consists of two sections, each section is fabricated on a printed circuit board four inches square. A photograph of the component side of the 111 MHz PLL oscillator board is given in Fig. 35. The main elements are standard Frequency Synthesizer components that are commercially available (Motorola MECL components, Ref. 13). The count-down circuit is hard wired for counting down from 111 to 1 MHz but it can be readily changed for other values. Photographs of the MLSO circuit board are given in Figs. 36 and 37. The SAW delay lines and filters are evident in Fig. 36. The 111 MHz SAW filter and its amplifier were added after the circuit board layout had been designed and fabricated; it can be seen that some improvisation was required in order to include them within the package. A shield was also added to separate the MLSO section from the multiplier section. All of the other components are seen in Fig. 37. These include various amplifiers, a transformer to provide a choice of signal polarity, some variable miniature potentiometers to allow for the signal level adjustments, and a length of coax (an expedient measure to adjust the MLSO loop delay time). Separate amplifier bias terminals are provided for gain control.

The output spectrum of the stabilized comb generator operating at 333 MHz is shown in Fig. 38. Ten lines within $\pm$ 3 dB in amplitude are found in the main lobe. One line of the spectrum, the one at the injected signal frequency, is larger than the rest. This signal line stands out because it contains a continuous component

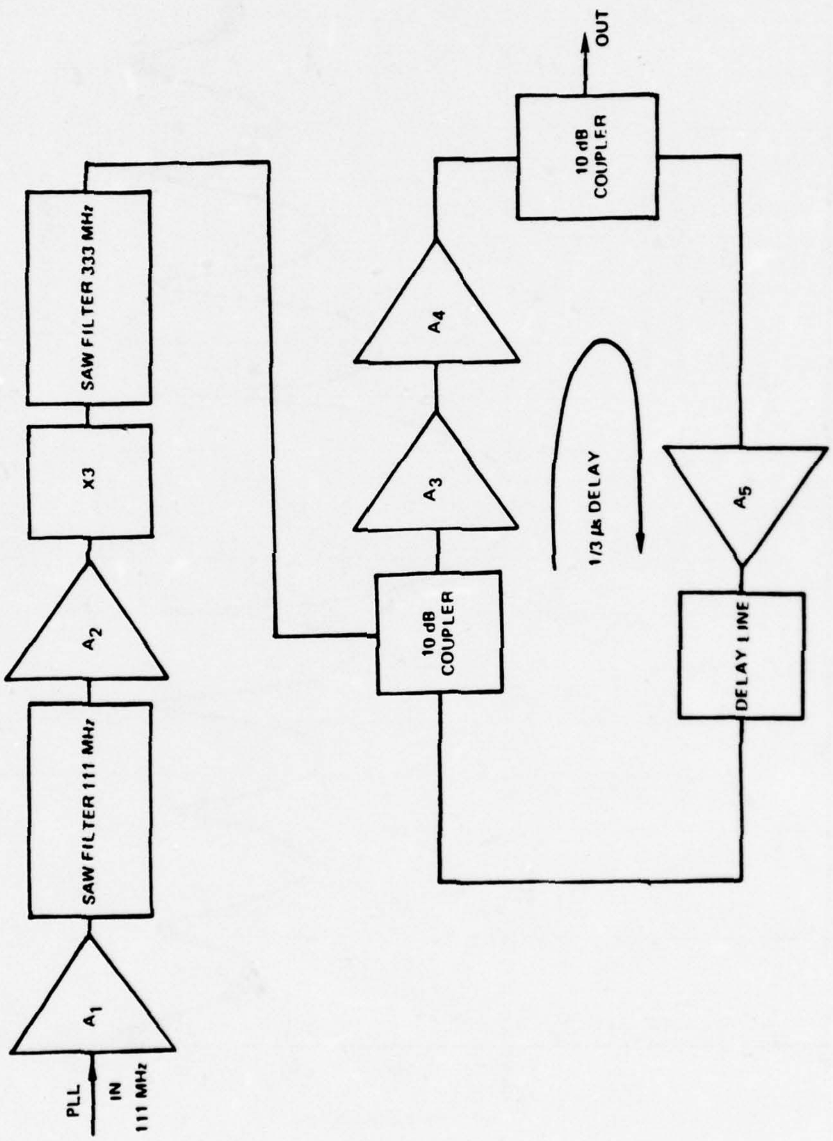
FIG. 33

SAW FILTER AT 333 MHz

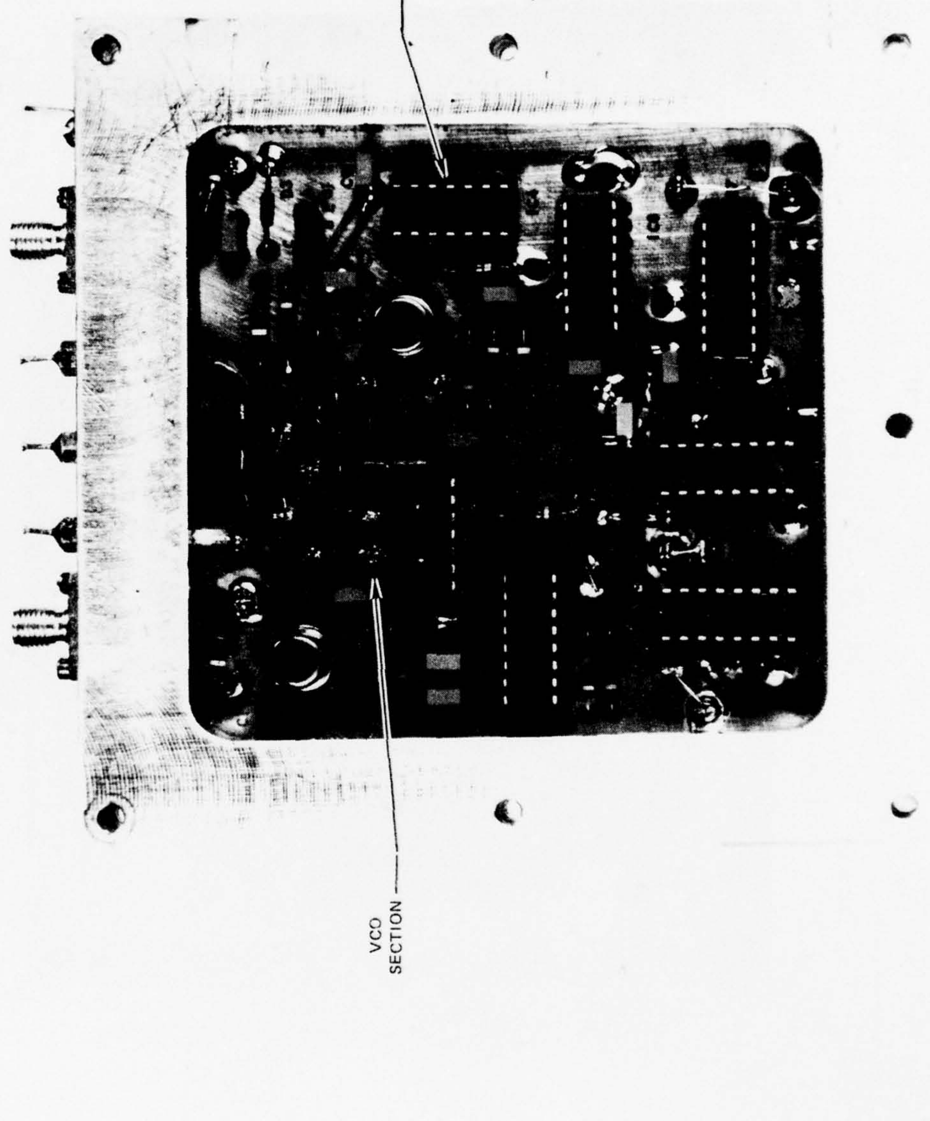



77–08–230–3

BLOCK DIAGRAM – 333 MHz COMB GENERATOR

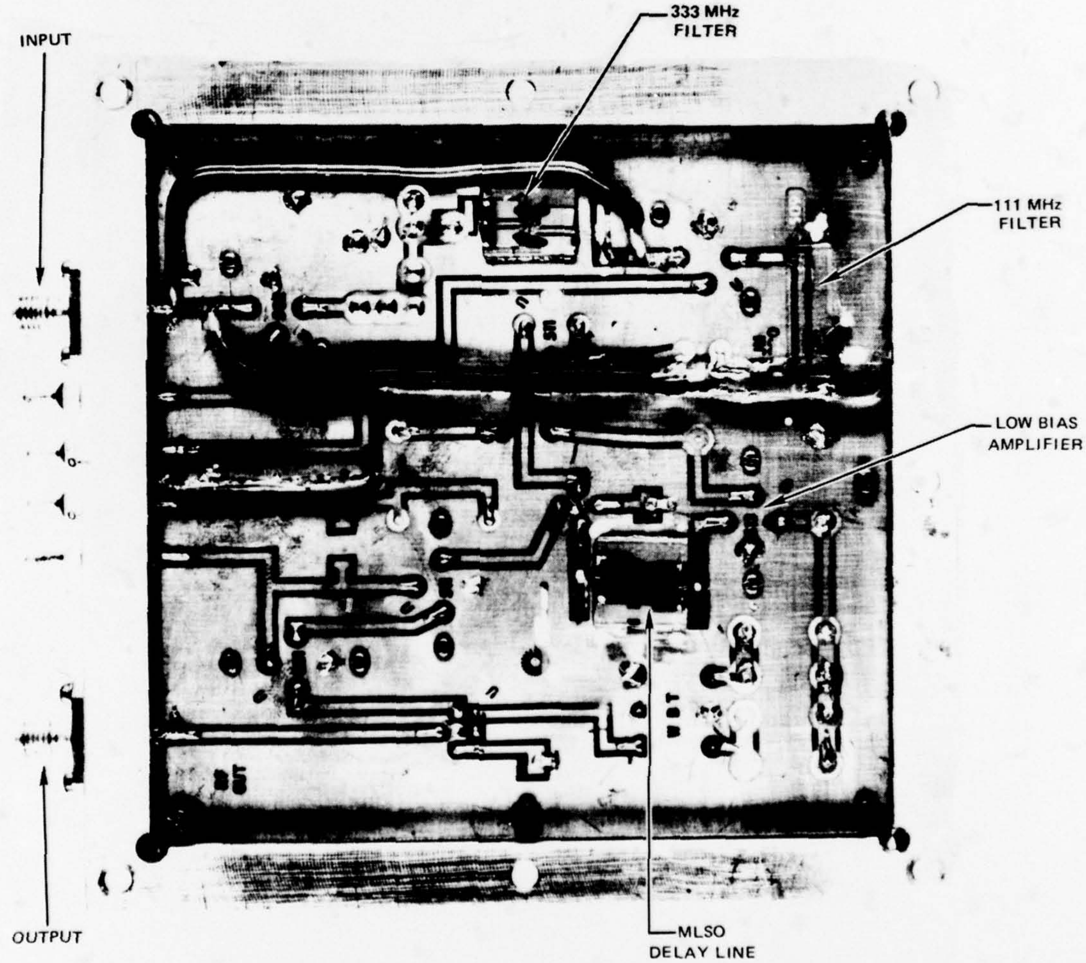



77–08–276–1




PHOTOGRAPH OF PHASE LOCKED LOOP SIGNAL SOURCE —COMPONENT SIDE

**PHOTOGRAPH OF MLSO INTERCONNECTION SIDE**



## PHOTOGRAPH OF MLSO COMPONENT SIDE

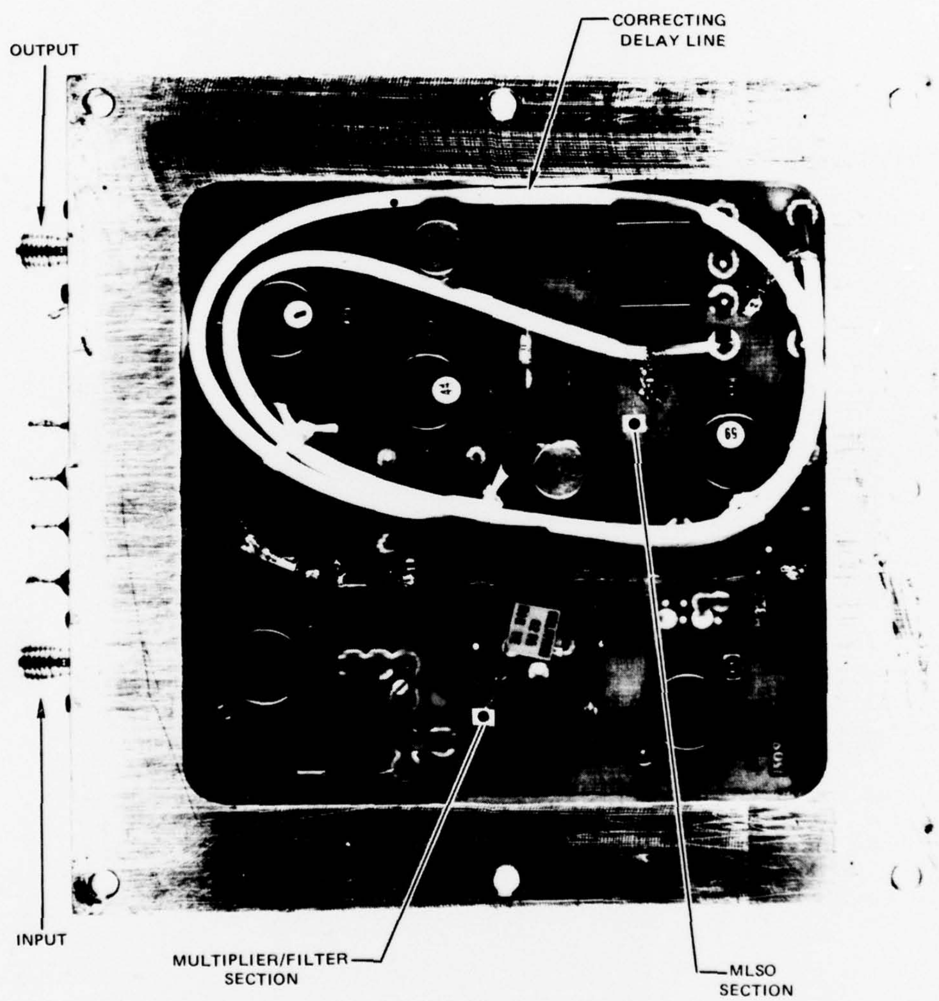
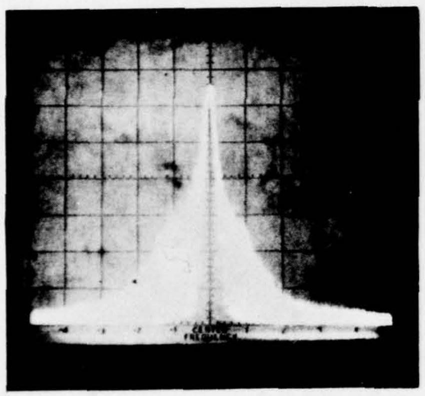


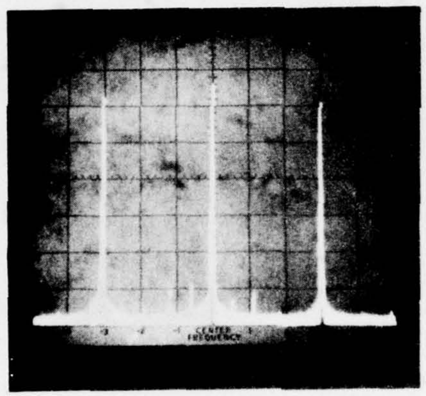
FIG. 38

OUTPUT SPECTRUM OF STABILIZED 333 MHz COMB GENERATOR



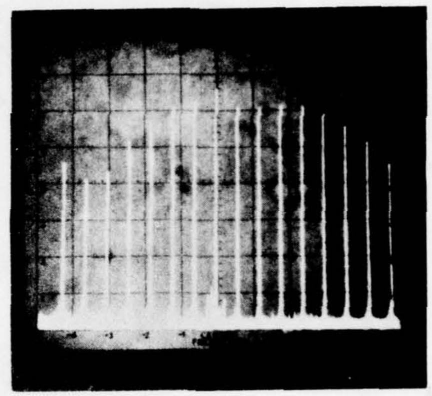
a) CENTER LINE

10 KHz/DIV, 1 KHz BW



b) CENTRAL LINES

1 MHz/div, 10 KHz BW



c) MAIN LOBE

5 MHz/div, 10 KHz BW

VERTICAL SCALE 10dB/div



77–08–230–6

while the rest of the lines result only from the rf pulse. In the frequency synthesizer a simple correction could be made for this by making that frequency channel have somewhat larger attenuation. Alternatively, the CW locking signal could be introduced as a pulsed signal that overlaps the circulating pulse. For this increased complexity in operation, the average energy in the locking signal would be reduced without reducing the peak level during the period of time when the two are interacting nonlinearly. The spurious signals all fall below the levels set by the requirements of the program (Fig. 38); but the FM noise level up to about 30 kHz away from the carrier does exceed the program requirements. The following table lists FM noise levels for different situations.

TABLE III

FM Noise Close to the Carrier
dBc Per Hertz

| | | | | MLSO | | |
|---|---|---|---|---|---|---|
| $\Delta$f-kHz | Required | Mult. * | PLL | Low Drive | High Drive | Free Running |
| 10 | -80 | -90 | -75 | -70 | -70 | -80 |
| 20 | | -100 | -90 | -87 | -82 | -90 |
| 40 | -95 | -105 | -105 | -92 | -100 | -95 |

* Frequency Multiplier driven by laboratory oscillator

The FM noise in close to the carrier in Fig. 38 and Table III appears to be due to that originating in the PLL oscillator. The degradation in noise performance between the PLL and the MLSO is consistent with that expected from frequency multipliers. The reduction in FM noise near the carrier can be implemented by further raising the Q of the voltage tuned oscillator circuit. Another alternative, which was not included in the scope of the original program, would have been to implement the increased circuit Q through the use of a voltage tuned SAW oscillator that now appears possible (Refs. 14, 15). The FM noise from the free running MLSO, Table III, is seen to meet the FM noise requirements; therefore, a single spectral line SAW oscillator, i.e., CW oscillator, with voltage tuning should easily provide the desired low noise source for injection locking the MLSO.

The two circuit boards of the 333 MHz comb generator, at present, have the following power supply requirements: PLL oscillator -- 2 mA at +15 volts, 30 mA at - 15 volts and 335 mA at + 5 volts; MLSO -- 96 mA at 24 volts, 1.2 mA at 15 and 36 mA at 12 volts. The PLL requires 2.2 watts of power and the MLSO requires 2.7 watts.

### 3.5 The 828 MHz Comb Spectrum Generator

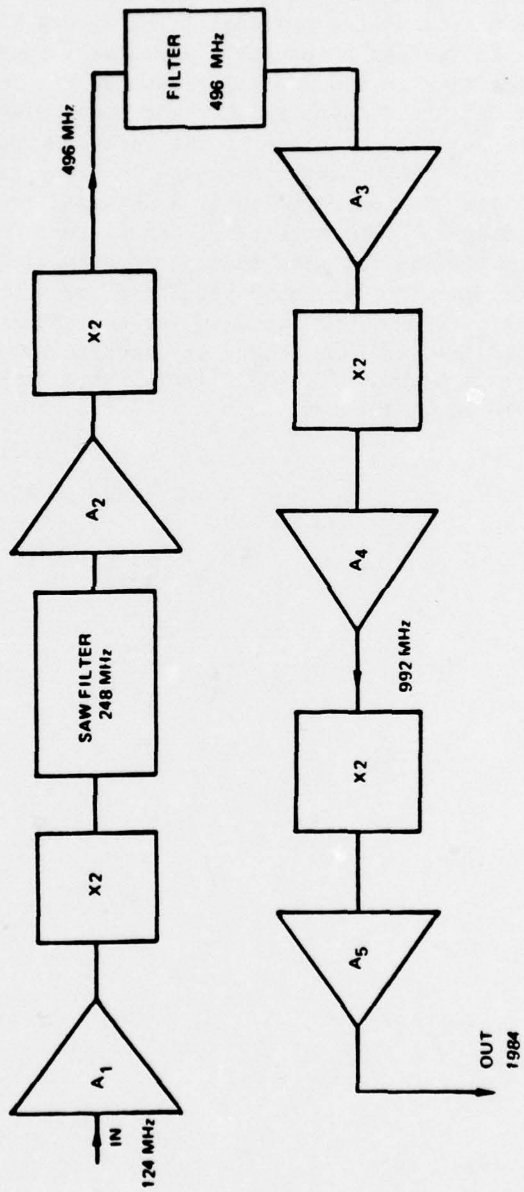
The 828 MHz comb spectrum generator is quite.similar to the one at 333 MHz. The block diagram of Fig. 34 contains all of the required components except for the addition of a frequency doubler just before the input coupler to the MLSO. The PLL however, must now operate at 138 MHz and the times three frequency multiplier provides a signal at 414 MHz. With the addition of a frequency doubler, a signal at 828 MHz is obtained. The input signal would typically be suppressed to a value 25 dB below the output signal. The delay line for the 828 MHz MLSO has the characteristics shown earlier in Fig. 16.

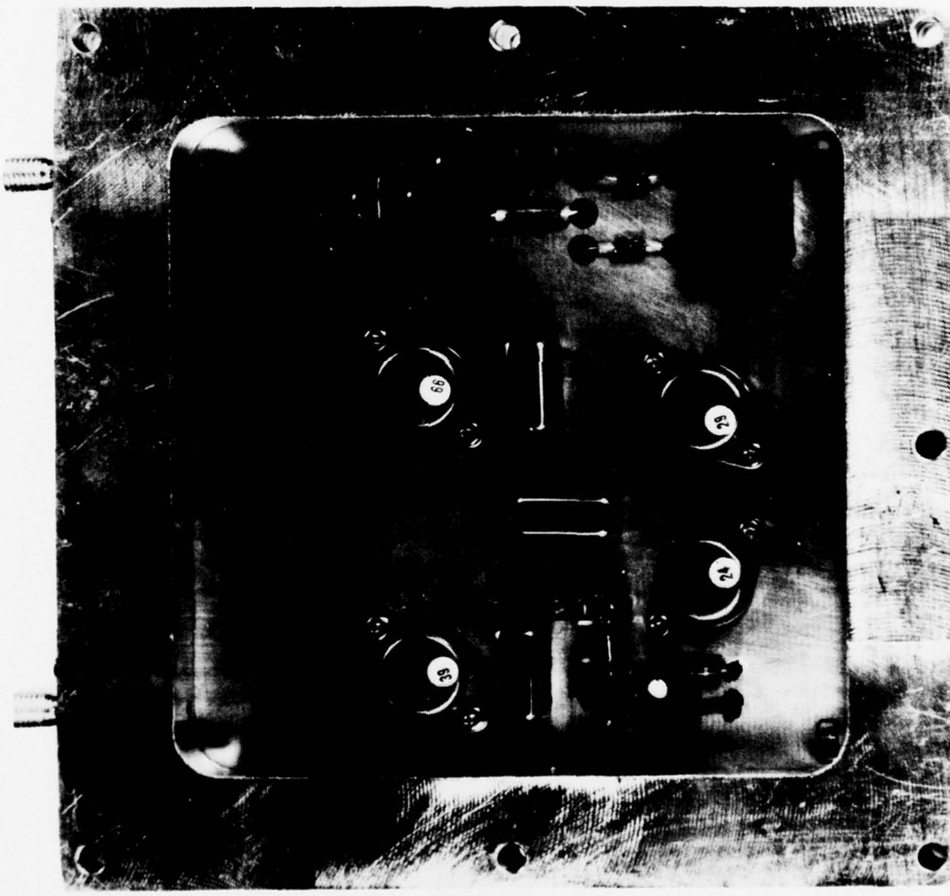
Although the main effort in the present work was on the 333 MHz comb generator, some preliminary operation was obtained at 828 MHz. The circuit board was that designed for 333 MHz. Mode locked operation was obtained; however, the bandwidth of the comb spectrum obtained was not wide enough to provide the desired number of lines. Since the transducer response (Fig. 16) was adequate, this result indicates that the 828 circuit board must be designed to provide for better broad band matching to the other components. The significant result here was that a reduced bias voltage amplifier for the 800 MHz range provides the required nonlinear action for Mode Locked operation.

## 4.0 SINGLE FREQUENCY SOURCE FOR 1984 MHz

The 1984 MHz source is shown in the block diagram in Fig. 39. It consists of a chain of very much miniaturized commercial doublers with SAW filters strategically placed in the chain to remove the residual 1 MHz spaced lines generated by the PLL oscillator and also to further attenuate any residual input signals leaking through the doublers. In addition to the SAW filter at 248 MHz in the chain, a back up filter operating at 496 MHz is also shown. The block diagram does not contain a final filter that might be required to clean up the residual spurious signals that would be spaced by at least 124 MHz intervals around the 1984 carrier. The design of that filter will depend upon what is revealed by a detailed evaluation of the circuit shown in the block diagram. The multiplier chain, for test purposes was fabricated and operated without the filters with satisfactory results. In view of the effort expended on the development of the successful new ideas that evolved for the 333 MHz comb generator, this portion of the program was not emphasized. A photograph of the component side of the 1984 MHz source is shown in Fig. 40, It is fabricated on a 4 inch square circuit board. The SAW filters, when fabricated, would be mounted on the other side of the circuit board.

BLOCK DIAGRAM – 1984 MHz SIGNAL GENERATOR





PHOTOGRAPH OF MULTIPLIER CHAIN AT 1984 MHz–COMPONENT SIDE

# 5.0 CONCLUSIONS AND RECOMMENDATIONS

The work that has been completed on the SAW signal sources has been very encouraging with respect to meeting the program goals for FM noise and spurious signal levels particularly with the 333 MHz comb generator. The 333 MHz comb generator, the design vehicle, is basically completed with operation very close to satisfying the program requirements. The other signal sources received less emphasis because of the need to take advantage of the new ideas that evolved during the 333 MHz development. These additional ideas have led to the realization of a practical comb spectrum generator based upon the characteristics of the Mode Locked SAW Oscillator. With the results obtained in this program, development can now proceed with the remaining signal sources. An important part of this program has been the application of SAW filters to help meet the specified goals.

The signal sources were fabricated on printed circuit boards that are 4 inches square. The circuit boards are actually suspended within the aluminum frames so that the frames can be stacked up and bolted together with thin metallic shields between them for electrical isolation. From the photographs of the circuit boards it is evident that it will be possible to reduce significantly the size of the components.

The developmental efforts remaining for obtaining practical prototypes signal sources include the following:

1. Size reduction

2. Fine adjustments in operating frequencies controlled by the SAW components

3. Broadbanding the 828 MHz feedback loop

4. Design and fabricating the addition SAW filters for the remaining signal sources.

It would then be desirable to conduct further research on the problem of extending the working temperature range. The first step would be to gain information by means of temperature cycling on the temperature limitations contributed from the various components in the circuit. The next step would be to overcome these limitations. Aside from straightforward techniques directed at the individual components, voltage tuning of SAW oscillators and of the MLSO is an area of research that could lead to wider temperature ranges of operation.

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# APPENDIX II

## SPECIFICATIONS

Sub-Line Item 0001AA - A stabilized and synchronized Surface Acoustic Wave (SAW) comb frequency spectrum generator will be designed, fabricated, and evaluated. A Mode-Locked SAW Oscillator (MLSO) will be developed to have 333 MHz center frequency and 1 MHz crystal controlled synchronization reference. The MLSO device will be designed to output 9 comb lines separated by 3.0 MHz over the 321 to 345 MHz range. The key goal of this development work will be to demonstrate synchronization of the coherent comb line output to the 1 MHz reference over a temperature range exceeding 10 to 35°C. The 1 MHz reference will be selected to provide a stability of 1 ppm or better over this temperature range. Additional specifications for the MLSO device are:

Power Output, 2 dBm
Output flatness, 321 to 345 MHz, ±3 dB
Spurious frequency suppression, at least 50 dB for frequencies above 370 MHz
FM noise requirement for low frequency comb:
less than -64 dBc/Hz ± 1 kHz from any tone
less than -84 dBc/Hz ± 10 kHz from any tone
less than -95 dBc/Hz ± 40 kHz from any tone
less than -97 dBc/Hz ± 100 kHz from any tone
less than -108 dBc/Hz ± 1 MHz from any tone
less than -108 dBc/Hz ± 1.5 MHz from any tone
Spurious requirement for low frequency comb:
less than -22 dBc ± 10 kHz from any tone
less than -32 dBc ± 40 kHz from any tone
less than -34 dBc ± 100 kHz from any tone
less than -44 dBc ± 1 MHz from any tone
less than -47 dBc ± 1.5 MHz from any tone

Sub-Line Item 0001AB - A stabilized and synchronized SAW comb frequency generator similar to the above but with 828 MHz center frequency and 1 MHz crystal controlled synchronization reference. The technical goals for the MLSO device will then be to provide 10 comb lines centered at 828 MHz and spaced by 24.0 MHz. RADC/ETEM will fabricate and supply two Y-cut, Z-orientated lithium - niobate 828 MHz delay lines with a fundamental band width which will provide 10 frequency lines covering a 216 MHz band width. UTRC will furnish the design for these delay lines and will work closely with RADC/ETEM during their fabrication. The additional technical specifications will be

Power output, 2 dBm
Output flatness, ± 3dB over the device 3 dB bandwidth
Spurious frequency suppression, at least 50 dB down at frequencies below 620 MHz and above 1200 MHz

Synchronization of MLSO output by a 1 MHz crystal controlled reference, 10 to 35°C

FM noise requirement for high frequency comb:
less than -64 dBc/Hz ± 1 kHz from any tone
less than -84 dBc/Hz ± 10 kHz from any tone
less than -95 dBc/Hz ± 40 kHz from any tone
less than -96 dBc/Hz ± 100 kHz from any tone
less than -108 dBc/Hz ± 1 MHz from any tone
less than -122 dBc/Hz ± 8 MHz to ± 12 MHz from any tone
Spurious requirement for high frequency comb:
less than -22 dBc ± 10 kHz from any tone
less than -32 dBc ± 40 kHz from any tone
less than -34 dBc ± 100 kHz from any tone
less than -44 dBc ± 1 MHz from any tone
less than -63 dBc ± 10 MHz to ± 12 MHz from any tone

Sub-Line Item 0001AC - A crystal controlled local oscillator will be designed, fabricated, and evaluated using a commercially available 1 MHz crystal controlled reference, two high precision SAW delay line channels, a low order semiconductor frequency multiplier, and an output stage, buffer amplifier. The unit will use one SAW delay path to control a 62 MHz precision oscillator which is subharmonic locked to the 1 MHz reference. A second SAW delay path will control a 496 MHz oscillator which is locked to the 62 MHz device. A X4 semiconductor mixer will be utilized to give the desired 1984 MHz output frequency and a buffer amplifier will be utilized to provide output circuit isolation and a sufficient output power level. The specifications for this unit will be:

Center frequency, 1984 MHz
Power Output, 0 dBm minimum
Frequency stability, 1 ppm or better
Temperature range, 10 to 35°C
FM noise requirement:
less than -64 dBc/Hz ± 1 kHz from 1984
less than -84 dBc/Hz ± 10 kHz from 1984
less than -95 dBc/Hz ± 40 kHz from 1984
less than -96 dBc/Hz ± 100 kHz from 1984
less than -108 dBc/Hz ± 1 MHz from 1984
less than -110 dBc/Hz ± 4.5 MHz from 1984
no noise limit from 0 to 754 or 1228 to 1747 MHz less than -122 dBc/Hz from 754 to 1228 MHz and from 1747 to 1976 MHz
less than -122 dBc/Hz from 1992 to 2221 MHz
no noise limit above 2221 MHz
Spurious requirement:
less than -22 dBc ± 10 kHz from 1984 MHz
less than -32 dBc ± 40 kHz from 1984 MHz
less than -34 dBc ± 100 kHz from 1984
less than -44 dBc ± 1 MHz from 1984
less than -50 dBc ± 5 MHz from 1984
less than -20 dBc from 0 to 754 MHz and from 1228 to 1420 MHz
less than -20 dBc from 1440 to 1480 MHz and from 1500 to 1747 MHz
less than -65 dBc from 754 to 1228 MHz and from 1420 to 1440 MHz
less than -65 dBc from 1480 to 1500 MHz and from 1747 to 1974 MHz
less than -65 dBc from 1994 to 2221 MHz
less than -20 dBc above 2221 MHz

# APPENDIX III

## OPERATION OF THE 333 MHz COMB GENERATOR

The 333 MHz Comb Generator consists of two circuit packages that are bolted together. One package contains the Mode Locked SAW Oscillator together with some input circuitry and the other contains the Phase Locked Loop Oscillator. A short length of semi-rigid coaxial cable has been connected between the output of the PLL and the input of the MLSO.

The power supply requirements, as indicated on the appropriate terminals of the components include:

| | | |
|---|---|---|
| PLL | +15 volts, | 2.1 ma |
| | -15 volts, | 30 ma |
| | + 5 volts, | 335 ma |
| MLSO | 24 volts, | 96 ma |
| | 15 volts, | 1.2 ma* |
| | 12 volts, | 36 ma* |

The circuit configuration and adjustment is such that the comb generator is self-starting. The proper input signal level to the PLL is 500 mV peak to peak. It results in an 80 mV peak to peak signal at the input of the MLSO. The output signal from the MLSO is 580 mV peak to peak.

The output frequency of the comb line that corresponds to the injection locking signal is 332.830 MHz. The corresponding input reference signal frequency is 0.99949 MHz. The condition of injection locking can be ascertained with a spectrum analyzer by noting when the locking signal coalesces with the free running signal. Alternatively, if a broad band oscilloscope is triggered by the injected signal, the instantaneous waveform of the rf pulse from the MLSO will be stationary and well defined.

* These two terminals are wired together with a dropping resistor so that 15 volts applied gives the correct operating conditions.

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HIGH FREQUENCY SIGNAL SOURCES USING SURFACE ACOUSTIC WAVE (SAW)--ETC(U)
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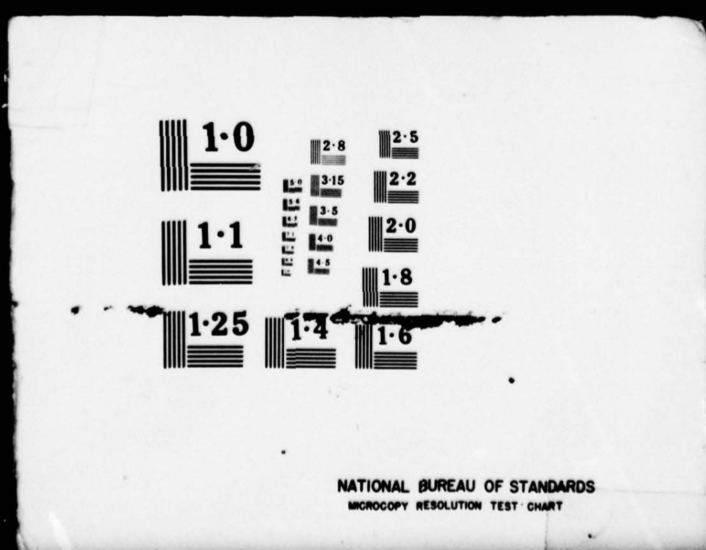

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RADC-TR-77-399
Final Technical Report - F19628-76-C-0263
November 1977

HIGH FREQUENCY SIGNAL SOURCES
USING SURFACE ACOUSTIC WAVE
(SAW) TECHNOLOGY

Errata

Replace Page 34 in subject report with attached Page 34.

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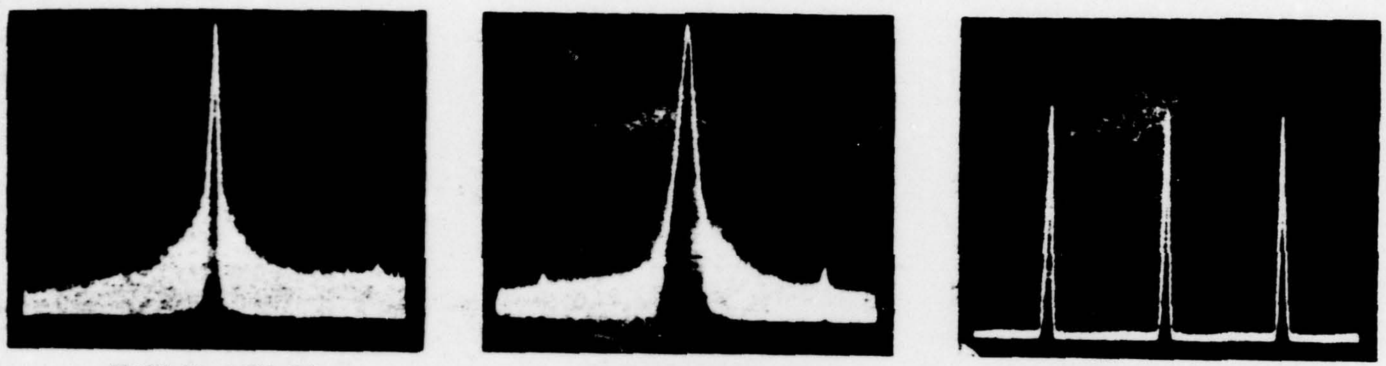
FREE RUNNING MLSO SIGNAL CHARACTERISTICS AT 333 MHz – COMB SPECTRUM



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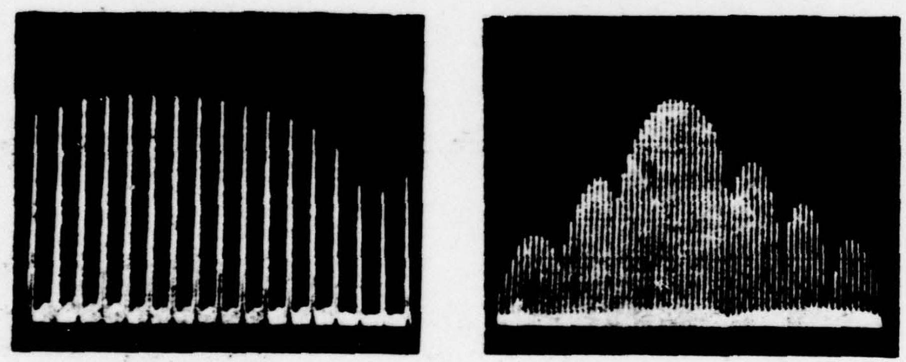
100 KHz/div, 10 KHz BW

1 MHz/div 30 KHz BW



5 MHz/div, 100 KHz BW

20 MHz/div, 100 KHz BW

VERTICAL SCALE 10dB/div